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U.S. NAVY REQUIREMENTS FOR UNDERWATER SOUND TRANSDUCER CALIBRAT--ETC(U)
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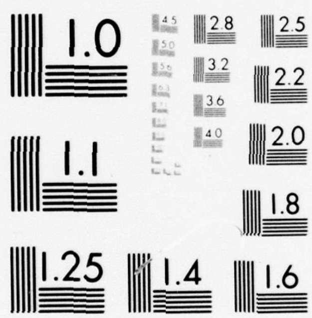

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U.S. Navy Requirements for Underwater Sound Transducer Calibration and Test Facilities,

A Study Prepared by
The Underwater Sound Advisory Group
for the
Chief of Naval Research

(10) D. E./Andrews, C. L./Bartberger,
W. F./Curtis, R. A./Frosch G. S./Harris

(11) 1 March 1963

(12) 66p.

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
Washington, D.C.

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PREFACE

In March 1962 the Chief of Naval Research requested the Underwater Sound Advisory Group to undertake "a comprehensive study of the transducer calibration problem and . . . of the facilities required to meet present and future Navy needs." This report summarizes the results of that study and furnishes a carefully developed set of "Recommendations" for action to implement the conclusions reached. A preliminary report setting forth a tentative body of recommendations was furnished the Chief of Naval Research in June 1962.

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CNR LETTER REQUESTING STUDY

DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON 25, D. C.

IN REPLY REFER TO
ONR:468:AWP:kf

7 MAR 1962

From: Chief of Naval Research
To: Dr. H. L. Saxton, Chairman, Underwater Sound Advisory Group

Subj: Transducer calibration facilities; recommendations for

Ref: (a) Undersea Warfare Research and Development Planning Council Report of 11 Oct 1960 entitled, "Technical Facilities Required for Navy Supported Research Relating to Undersea Warfare". See also report to Undersea Warfare Planning Council on Major Acoustic Transducer Facilities requested by five laboratories (Encl (1) to NRL ltr 5520-466 ser 01245). See also "Major Acoustic Transducer Facilities", NRL ltr ser 2615-0205 (11018) of 25 Nov 1960
(b) "Report of Ad Hoc Committee on Bureau of Ships Needs for Acoustic Range Facilities", dtd June 2, 1960
(c) USAG Report entitled, "Ideal Program in Underwater Sound, Appendix 9", Sub Group Report on Research Instrumentation and Facilities

1. In earlier conversations between yourself as Chairman of the Underwater Sound Advisory Group and members of my staff, the need has been emphasized for a comprehensive study of the transducer calibration problem and the development of a clear picture of the transducer calibration facilities required to meet present and future Navy needs. It is requested that the Underwater Sound Advisory Group undertake this study.

2. I am particularly anxious that the study should be as complete and realistic as possible and that any recommendations for facilities be acceptable to the various technical bureaus and offices concerned. In looking at the calibration problem, attention should be given to the various and differing types of measurement required in research, development, production testing, evaluation, and maintenance and repair. The study should not be limited to conventional sonar transducers but should cover calibration of all types of underwater acoustic transducers, for example, those used in weapon guidance, influence and countermeasures. Attention should be given to new and anticipated trends in measurement techniques and the effects these will have on calibration facility requirements. It is my belief that the specific types of measurement actually required for the various purposes should be critically examined.

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3. The Underwater Sound Advisory Group should also include consideration of the requirements for specialized facilities for transducer testing such as high pressure calibration tanks.

4. A number of studies have already been undertaken in this area within recent years and they will undoubtedly provide background material. See, for example, references (a), (b), and (c).

5. I am appreciative of the magnitude of the task to be undertaken, which should culminate with specific facility recommendations including costs. It is desirable, however, that I have a preliminary report available to me by mid-June 1962.

L. D. COATES

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MEMBERS OF THE UNDERWATER SOUND ADVISORY GROUP
DURING 1962, THE PERIOD OF THE STUDY

D. E. Andrews, Chairman (1963)
U.S. Navy Electronics Laboratory

C. L. Bartberger
U.S. Naval Air Development Center

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David Taylor Model Basin

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G. S. Harris, Chairman (1962)
U.S. Navy Underwater Sound Laboratory

A. T. Jaques
U.S. Naval Ordnance Laboratory

C. M. McKinney
Defense Research Laboratory

H. L. Saxton, Chairman (prior to 1962)
Naval Research Laboratory

F. N. Spiess
Marine Physical Laboratory
Scripps Institution of Oceanography

A. W. Pryce (Code 468), Secretariat
Office of Naval Research

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U.S. Navy Requirements for Underwater Sound Transducer Calibration and Test Facilities

RECOMMENDATIONS

The Underwater Sound Advisory Group has made an extensive and careful study of (a) the U.S. Navy requirements for underwater acoustic transducer calibration and test facilities, and (b) the status of available and planned facilities as to their technical adequacy and workload capacity. It reached considered conclusions that serious deficiencies exist now and for the near future. The USAG thoroughly supports these recommendations and urges immediate action at high priority to avert even more serious deficiencies as the workload grows.

Coordination of acoustic facility planning is essential. USAG acting in its advisory capacity will continue to study acoustic calibration facility proposals and will make recommendations thereto as appropriate.

STANDARDS AND TECHNIQUES

It is recommended that:

*ONR
BuS
BuW
1. The continuing function of the U.S. Navy Underwater Sound Reference Laboratory as the source of transducer standards in the Navy never be impaired because of increased demands on this Laboratory for other work.

ONR
BuS
BuW
2. Increased emphasis be given to the research and development on new measurement techniques and instrumentation, particularly at USRL. Particular emphasis should be given to research on near-field calibration methods and engineering studies of automated calibration systems.

BuS
BuW
ONR
3. Near-field calibration of transducers be used when expedient, particularly in prototype and acceptance testing, and laboratories and contractors familiarize themselves with the technique. BuShips should develop calibration equipment using this technique for each major transducer type for shipyard use in production acceptance and fleet maintenance.

RESEARCH AND DEVELOPMENT BY IN-HOUSE AND CONTRACT LABORATORIES

To keep up with increasing demands, and to protect R and D against the encroachment of prototype and production testing, the Navy should promptly increase its facilities both for R and D and for procurement. It is recommended that:

For Deep-Water Facilities

BuS
4. The transducer calibration facility on Lake Pend Oreille be recognized as the primary facility in the west to meet the deep-water R and D needs of the Navy in-house and contract laboratories.

*The marginal designations indicate the bureaus concerned with the recommendation. The bureau principally concerned is underlined.

ONR 5. A transducer calibration and measurement facility be established on Lake Seneca, New York, as the primary deep-water facility in the east to meet the R and D needs of the Navy in-house and contract laboratories. USRL should operate this establishment.

To meet the current urgent need for this facility, the U.S. Naval Research Laboratory established its mobile test platform on Lake Seneca in calendar 1962 and is operating it initially. USRL should plan in detail an expansion of the above facility on Lake Seneca. USRL should take over the operation of the NRL platform by the end of calendar 1963, develop the central facility, and continue expansion of this facility to keep up with R and D requirements within the site limitations.

ONR 6. The proposal for the Tilly Foster Transducer Calibration Facility be withdrawn.

ONR *BuS* 7. A deep-ocean acoustic measurement capability be provided. The design and feasibility study of a stable ocean platform as proposed by NRL is strongly endorsed, and it is recommended that funding under AUTEC be provided for procurement and operation. It is further recommended that its maintenance and logistic support be provided by the general AUTEC authority with technical control vested in NRL.

For Local Open-Water Facilities

ONR 8. Expansion of open-water facilities at Orlando-Leesburg be limited to modest exploitation of the Leesburg site and limited to facility development primarily for standards work. No heavy handling capability is considered necessary.

BuW 9. The Bureau of Naval Weapons fund NADC for the development of a transducer calibration facility at Oreland, Pennsylvania. This funding should be initiated in FY'64 (reprogramming if necessary).

ONR 10. The request of NRL for an indoor open anechoic tank (50 ft diameter × 30 ft deep) be supported and funded.

BuS 11. Prototype and preproduction unit testing at USL's Dodge Pond facility be progressively reduced to utilize not more than 25 percent of the facility time, in order to accommodate USL's Research and Development requirements.

CNO 12. No open-water facility be provided the Naval Oceanographic Office until increased needs of the oceanographic and ASWEPS programs are established.

For Pressure Facilities

ONR 13. A high-pressure acoustic test facility be provided to USRL. A high-pressure tank with an anechoic working volume at least 20 ft in diameter and for pressures up to at least 3000 psi is required. High priority should be given its design and funding.

BuS 14. Tanks for hydrostatic tests for USL (4 ft diameter × 12 ft height; 15,000 psi) and for NRL (8 × 12 ft; 5000 psi) be funded and procured in FY'64.

ONR *BuS* *BuW* 15. The Navy laboratories develop techniques and engineering plans to meet the growing need for high-pressure acoustic testing and the pertinent parent bureaus provide for their timely procurement.

CONTRACTOR DEVELOPMENT

It is recommended that:

BuS *BuW* 16. Contractors be required to carry on their development work without using facilities of Navy in-house laboratories, except as these may be available on a not-to-interfere basis (within the 25 percent available).

PROTOTYPE AND PREPRODUCTION TESTING

It is recommended that:

ONR 17. A new acoustic test facility for the major portion of prototype and preproduction testing be established on Lake Seneca, New York, to be operated by USRL; and USRL be expanded as necessary to carry out this responsibility which is entirely in addition to that of recommendation 5.

ONR *BuS* *BuW* 18. Other in-house R and D laboratories should share in testing of those contracted items in which they have an R and D interest, but the maximum workload at their facilities in connection with such contract procurements should be limited to 25 percent (time/manpower) of their testing capability. When economically advisable, development testing at contractors' facilities should be extended through the prototype or preproduction stage, with supervision of final testing by Navy laboratories.

BuS *BuW* *ONR* 19. As an interim measure (until the recommendation 17 is implemented), for calibration and measurement of prototype transducers (not tested as parts of assembled systems), the bureaus distribute work equitably among Navy laboratories, including use of contractors' facilities as far as possible. Specifically, the prototype and preproduction testing at USL should be decreased, that of USRL/Orlando should remain about as it is, and that at other facilities should be increased. Assignments should take into account the technical capabilities of the different facilities. When this results in the necessity for these laboratories to work additional shifts in order to carry the workload of both R and D and preproduction testing, the bureaus should provide for, and fund, the extra billets required.

BuS 20. The Bureau of Ships procure and equip a special platform for the prototype testing of each new major sonar system, including the transducer(s). These platforms should be available in time for use in systems development by the contractor.

SHIPYARD TESTING

It is recommended that:

BuS 21. The Bureau of Ships fund in FY'64, two test tanks at Boston and one at Pearl Harbor to be of a size established by the requirements for near-field measurements. The tanks at Boston should be under cover for winter operation.

BuS 22. The Bureau of Ships study the potential and means of using near-field techniques for "in place" calibration of sonar transducers as installed in ships and submarines and provide such instrumentation, procedures, and training as required. Immediate planning should be initiated by the Bureau of Ships to provide for the greatly increased workload in fleet maintenance of installed transducers and transducer systems resulting from the new ship and submarine sonar systems planned for the 1965-1970 period.

BuS 23. The Bureau of Ships recognize the present and growing need for competent, well-trained personnel to staff shipyard test facilities and find means of procuring and training personnel and getting adequate civil service grades assigned.

CHAPTER 1

BACKGROUND

THE PROBLEM

Without the development of low-frequency transducers, the great advances in fleet sonars experienced since World War II would have been impossible. During the war, detection equipment utilized transducers only slightly over one foot in diameter. Today we have the SQS-26, which has a transducer 16 ft in diameter. World War II transducers weighed some 200 lb. That of the SQS-26 weighs 30,000 lb, and the Artemis projector weighs 650,000 lb. World War II transducers were of trifling size, weight, and complexity, compared with today's. Yet we are trying to develop and test today's transducers with facilities for the most part appropriate for World War II equipment. It is not surprising that the latest transducers have misbehaved in unanticipated ways and have generally failed to deliver the power output for which they were designed. Research and development can neither sustain a lead relative to attempted design nor analyze faults with its grossly inadequate facilities.

The material bureaus contract for new designs with a minimum performance specified. Before a design is accepted, a prototype must be subjected to acceptance tests requiring adequate facilities. For a transducer of the size of the SQS-26 there is no adequate facility. As a consequence, laboratories assigned the problem of testing must resort to devious approaches, involving the tests of pieces rather than the whole. This is not a satisfactory alternative to the test of the entire transducer in an adequate facility.

It was found as far back as World War II that many ships were not obtaining predicted performance with their sonars because of equipment difficulty which later was traced to defective transducers. The fleet felt the need for test facilities at naval stations where any transducer could be checked while the ship was in port, if there appeared to be a deficiency in the sonar performance. At that time some facilities were established. These took the form of tanks which could be used with pulse techniques to obtain indications of transducer sensitivity and beam patterns. Thus, deficiency in the transducer itself could be discovered and corrective measures taken. As transducers were increased in size, the old methods of tests in tanks became meaningless, because the dimensions of the tank would not accommodate far-field measurements. In the past few years studies have been aimed at near-field techniques which could give a meaningful indication of transducer performance. Considerable progress has been made, but the problem is not yet fully solved.

The primary reason for the present difficulty is that facilities development has not gone hand in hand with transducer advances, as it should. The lag in meeting facility requirements has greatly retarded the research-and-development effort which could have otherwise anticipated problems and could possibly have corrected designs before prototypes were built. At the very least, adequate facilities would have afforded opportunity to discover faults in prototypes and to study the reasons therefor.

It is apparent to all involved in transducer calibration and testing that the U.S. Navy is now at a crossroad. A decision must be made as to the course to be followed in providing facilities, and prompt, decisive action must be taken.

PREVIOUS PROPOSALS

Various individual laboratories have made repeated attempts to remedy the situation. NRL has carried one facility plan after another to the costing stage, only to fail to muster support. Their surveys covered many sites in the Potomac River, including Fort Washington, Indian Head, Fort Belvoir, and Quantico. All of these sites were seriously considered. The Rocky Gorge Dam site was surveyed and considered. A favorable James River site was considered. Several deep holes in Chesapeake Bay were surveyed. NRL has now modified a barge for a mobile test platform, moved it into Lake Seneca, and has begun using it for R and D measurements.

USRL made repeated proposals for an installation at Tilly-Foster, New York. Their attempts to satisfy all persons concerned resulted in an ultimate cost which was not accepted.

NEL has recognized the problem and has been backed in developing Lake Pend Oreille, the only Navy facility which is adequate for today's problems with respect to water depth. NEL is also in the process of providing an increased (50 ton) weight-handling capacity. The main drawbacks of this facility are geographic remoteness, particularly from eastern laboratories, and its limitations in work load.

PREVIOUS STUDIES

In October 1959, the Assistant Chief of the Bureau of Ships for Research and Development appointed an ad hoc committee to consider the requirements of BuShips and its laboratories for transducer calibration facilities. The USW R and D Planning Council studied the same problem on a Navy-wide scale later in 1960. The BuShips ad hoc committee, pointing to the inadequacy of acoustic test facilities in the U.S. Navy, recommended a major central facility on the east coast and means for testing in deep ocean water. Action has been taken on the latter recommendation, with the result that AUTEC is planning an ocean facility.

TECHNICAL REQUIREMENTS

Since the transducer is usually the key component in any piece of underwater sound equipment, it is not surprising that there are a wide variety of transducer types to be considered in a survey of needs and requirements for calibration. The more important types include:

1. ASW surface ship active sonar transducers
2. Submarine sonar (active and passive) transducers
3. Fixed-station surveillance sonar, active and passive
4. Helicopter-borne sonar transducers
5. Sonobuoy transducers
6. Acoustic torpedo transducers
7. Acoustic mine mechanism transducers
8. Minehunting transducers
9. Acoustic minesweep transducers
10. Acoustic communications transducers
11. Acoustic navigation system transducers
12. Depth-sounding transducers
13. Standard calibration transducers
14. Noise-measurement transducers
15. Transducers for underwater research (propagation, etc.).

Many distinct steps are involved in the history of a transducer from the research stage to production acceptance, and calibrations are required for all of the different versions of the device. These stages of development correspond to the broad categories of calibration requirements tabulated below.

1. Research and development (primarily by Navy and nonindustrial concerns)
2. Contractor development
3. Prototype evaluation
4. Preproduction testing
5. Production acceptance testing
6. Fleet repair and maintenance testing
7. Calibration of installed equipment.

On most transducers, it is required that a great many separate measurements be made. Acoustic calibration measurements are made to determine the following characteristics:

1. Source level and receiver sensitivity
2. Directivity patterns
3. Complex impedance
4. Efficiency.

The above characteristics are generally determined as a function of the following parameters:

1. Frequency
2. Power level (for nonlinear, cavitation, etc., effects)
3. Static pressure
4. Temperature
5. Duration of tests (life tests).

Other data which are generally obtained in connection with calibration relate to mechanical resonances, corrosion, water leakage, electrical leakage, etc.

The broad technical requirements for a transducer calibration facility are:

1. Sufficient size (depth and lateral extent) to permit valid noninterference (free-field) calibrations to be made on the particular transducer under test. Some transducers require only a few feet of depth, while others require hundreds or even thousands of feet. The same statement is true for separation distance. The more technical aspects of these requirements are covered in Chapter 2.

2. Sufficient handling capacity in terms of size and weight. Size may range from a few inches to hundreds of feet, and weights from a few ounces to hundreds of tons.

3. A capability for calibration at the ambient conditions of pressure and temperature under which the transducer is designed to operate.

4. Capability for testing at the rated power level of the transducer.

5. Sufficient capacity to eliminate the accumulation of large backloads of work.

6. Geographic accessibility. Proximity to the customer and adequate transportation facilities are important.

The range of transducer sizes, weights, frequencies, and operating depths involved clearly shows that:

1. Many of the desired tests can be performed in existing local facilities. These are technically adequate for most transducers operating at a frequency of 10 kc or above.

2. The great bulk of low-frequency measurements, particularly of large arrays, requires technical facilities well beyond any now available except at Lake Pend Oreille.

3. Any facility for handling the larger low-frequency arrays should be capable of handling heavy loads and supplying high power.

4. Any facility for low frequency should include automatic measuring equipment and computers for computation of deduced parameters and automatic plotting to enable operation at very high efficiency and hence accommodating a high work load.

It has been the intent of this study to consider all of the factors discussed in this section in assessing the needs and in preparing recommendations concerning calibration facilities.

CHAPTER 2

TECHNICAL CONSIDERATIONS

GENERAL CALIBRATION TECHNIQUES AND FAR-FIELD MEASUREMENTS

The optimum technique for calibrating a transducer is a function of the characteristics of the particular transducer, primarily the frequency, dimensions, bandwidth, and mode of operation (e.g., pulse, cw, etc.). It is difficult to express the limits of a given calibration facility in terms of frequency and transducer size, but it is comparatively easy to determine whether a given transducer can be calibrated in a particular facility. The directivity pattern of the transducer is often a most important factor to consider in planning the calibration arrangement and procedure (Refs. 1-6).

Most transducers are employed as far-field devices, and for this reason it is desirable to have far-field calibrations when feasible. In order to obtain a valid far-field calibration, it is required that the transducer under test (considered as a hydrophone receiving from a point source) be insonified by essentially a plane wave.

The practical far-field criteria are:

$$R \geq d^2/\lambda \quad \text{or} \quad R \geq n^2\lambda \tag{1}$$

$$R \geq 5d \quad \text{or} \quad R \geq 5n\lambda \tag{2}$$

where R is the distance from the source, d is the maximum dimension of the transducer, λ is the wavelength of the sound received, and $n = d/\lambda$. Equation (1) insures that the wavefront curvature does not introduce relative phase shifts exceeding 45 degrees. The criterion of Eq. (2) insures that the divergence loss caused by spherical wave divergence is not sufficiently variable over the transducer face to modify the results appreciably, regardless of its orientation. Equations (1) and (2) also apply to the far field of a source under test. The required separation of the monitoring transducer and the transducer under test, as determined by these two criteria, is shown in Fig. 1a and 1b (alternate forms of presentation).

The criteria just given apply to the case of one transducer being infinitely small. For the case of both transducers having appreciable dimensions, d_1 and d_2, the criteria are:

$$R \geq (d_1 + d_2)^2/\lambda \tag{3}$$

$$R \geq 5(d_1 + d_2)\ . \tag{4}$$

It is of importance to note that measurements may be made at ranges as short as

$$R = 0.5\ d^2/\lambda \tag{5}$$

and

$$R = 2d \tag{6}$$

if appropriate correction factors are used. Shorter ranges than those given by Eqs. (5) and (6) are open to question concerning the validity of a correction factor.

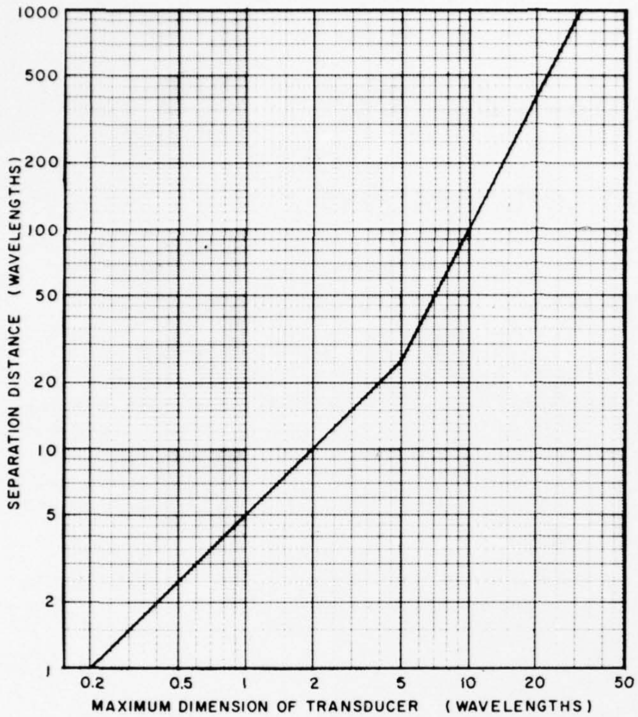

Fig. 1a. Minimum required transducer separation as a function of maximum dimension of transducer under test

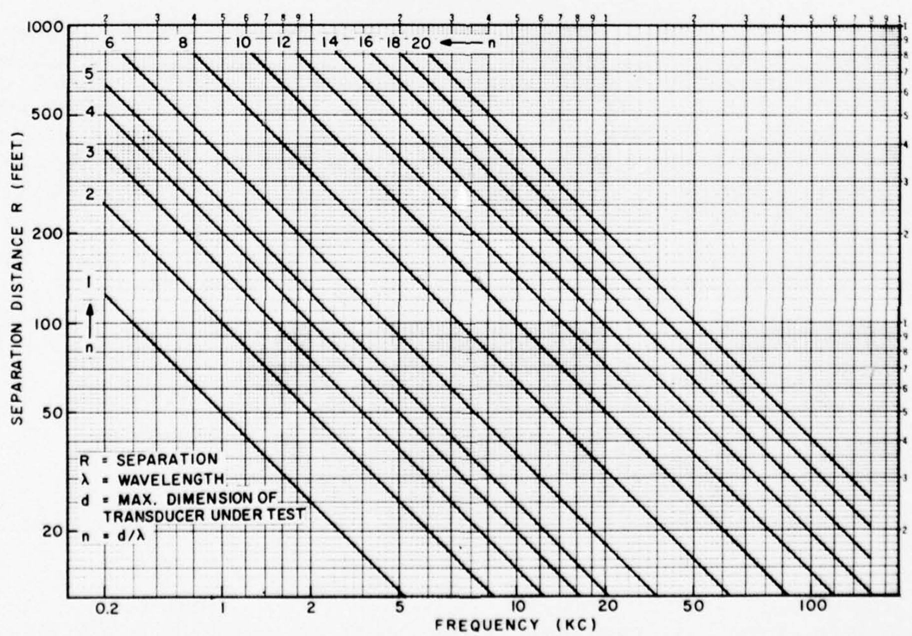

Fig. 1b. Minimum required transducer separation as a function of frequency and maximum dimension of transducer under test

It is essential in most instances to have the calibration made under free-field conditions. This last condition requires that energy arriving at the transducer by other than the direct path should be negligibly small or should arrive at a time other than when the calibration measurements are made. A number of techniques may be employed to reduce the intensity of reflected signals to an acceptable level. For precise measurement of the complete directivity pattern of a transducer, it is desirable that the level of reflected signals be at least 40 db below the level of the direct path signal. However, for most measurements a 20-db differential level is adequate. The most straightforward means of meeting this condition is to conduct the calibration in a body of water of sufficient size to insure that the reflected path is at least ten times as long as the direct path, thereby achieving the necessary attenuation of reflected signals as a result of spherical-wave divergence. If both the transducer under test and the monitoring transducer are placed at a depth midway between the water surface and the bottom and are separated by a distance R determined by Eqs. (1) and (2), then, providing the body of water has adequate lateral dimensions to reduce reflections from the sides, the minimum required water depth h is approximately 10 R, i.e.,

$$h \geq 10\ d^2/\lambda \tag{7}$$

$$h \geq 50\ d\ . \tag{8}$$

In applying these criteria, care must be taken to avoid transducer orientations which place the transducer beam in the direction of the reflected path while direct measurements are being made at angles away from the beam.

The minimum required water depth determined by Eqs. (7) and (8) may be obtained from Figs. 1a and 1b by multiplying the transducer separation by a factor of 10. This information is also plotted in a slightly different form in Fig. 2, which shows the maximum permissible transducer dimension as a function of both frequency and water depth.

It is evident that for large transducers these criteria lead to the requirement for very large bodies of water. For example, a transducer larger than 12 ft requires a water depth in

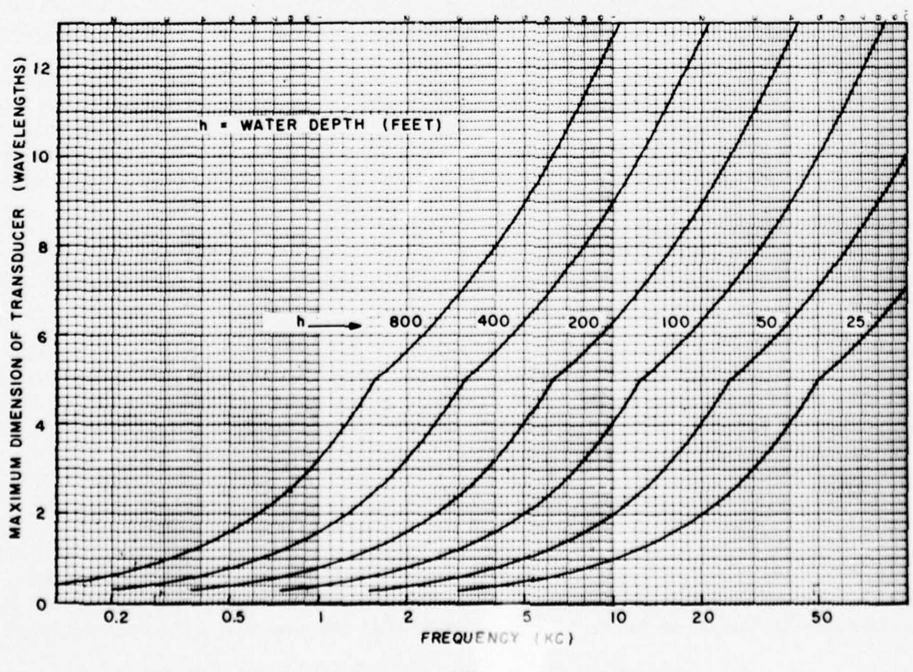

Fig. 2. Maximum permissible transducer dimension for calibration measurements using cw operation

excess of 600 ft. No inland lake in the eastern part of the United States will accommodate such a transducer.

Fortunately, there are techniques which often alleviate the severe depth requirement of ten times the separation. One of these techniques is to make the walls or boundaries nonreflective. High attenuation at low frequencies is difficult and costly to achieve, but not impossible. If the boundaries are sufficiently anechoic, reflection may be neglected. USRL recommends Insulcrete (concrete-sawdust) wedges. This material is inexpensive, retains its absorptive properties under high hydrostatic pressures, and has broad-band characteristics. Several rubber-base materials have good absorption characteristics at low pressures, but are not so effective at high pressures. Narrow-band or tuned absorbers have been developed also.

NEL has developed recently a new type of calibration pool, Transdec, in which boundary reflection is controlled. The shape of the pool is that of a canted ellipsoid of revolution. Reflections from the walls of the pool and from the air-water interface terminate in an absorptive sound trap which surrounds the lip of the pool. By the use of this technique the interference due to reflected energy is sharply reduced and the free-field test region is an appreciable portion of the total volume of the pool.

There is a class of techniques which takes advantage of transducer directivity. Proper use of transducer directivity is one of the most important considerations in the calibration of transducers. It is most useful when the horizontal expanse of the water is sufficient to neglect reflection from the side-wall boundaries. The application of these techniques, however, must be worked out for each individual case.

One method in this class is to orient the transducer so that signals reflected from a boundary are at a low intensity level. The usual procedure is to adjust the depth of the transducer so that the first null in the pattern will strike the surface at the point midway along the transmission path.

A second method is the use of a vertical-line monitoring transducer so placed that it discriminates against surface and bottom reflections. The price one has to pay for this is an increased separation distance (since a large dimension of the monitoring transducer contributes to the separation distance) and a stricter requirement on the orientation of the monitoring transducer, but often the advantage gained in reduction of depth is a more important factor.

A third method in this class is to place one transducer near the surface, taking advantage of surface reflection to generate a beam equivalent to that of an array composed of the actual transducer and its mirror image. The other transducer is then set at a depth which will place it in the first constructive interference lobe. This depth, of course, is a function of the frequency. This technique has been applied successfully in the calibration of radar antennas.

A significant reduction in the water-depth requirement can usually be achieved by employing pulsed operation. In general it is desirable to calibrate a transducer using the mode of transmission for which it has been designed, so that this method is especially applicable to pulsed sonars.

When pulsed operation is employed the interference generated by boundary reflections can be eliminated by "gating out" all but the direct signal. When this technique is used, however, it is necessary that the received pulse be of sufficient duration to reach steady state before any reflected signals arrive. For a transducer of small dimensions, the time to build up to 95 percent of the steady-state value is Q/f, where Q is the overall Q of the calibration system, including the transducer under test. If the transducer has appreciable size, an additional delay is caused by interaction between belements, for which an allowance should be made equal to the time required for the wave to sweep at least once over the maximum dimension d of the transducer. Also, in order to obtain a satisfactory measurement it is advisable to continue the pulse for an additional time equivalent to at least three cycles at the operating frequency. Adding all these time intervals and multiplying by the velocity of sound, one obtains the result that the difference in length Δr between the reflected path and the direct path should be at least

$$\Delta r = (Q+3)\lambda + d \quad \text{or} \quad \Delta r = (Q+n+3)\lambda . \qquad (9)$$

In facilities where depth is the limiting dimension, this criterion may be expressed in terms of the total depth h by the formula:

$$h = \sqrt{2R\Delta r + (\Delta r)^2} \tag{10}$$

where R is the test separation determined by Eqs. (1) and (2). A plot of h/λ as a function of n is shown for various values of Q in Fig. 3.

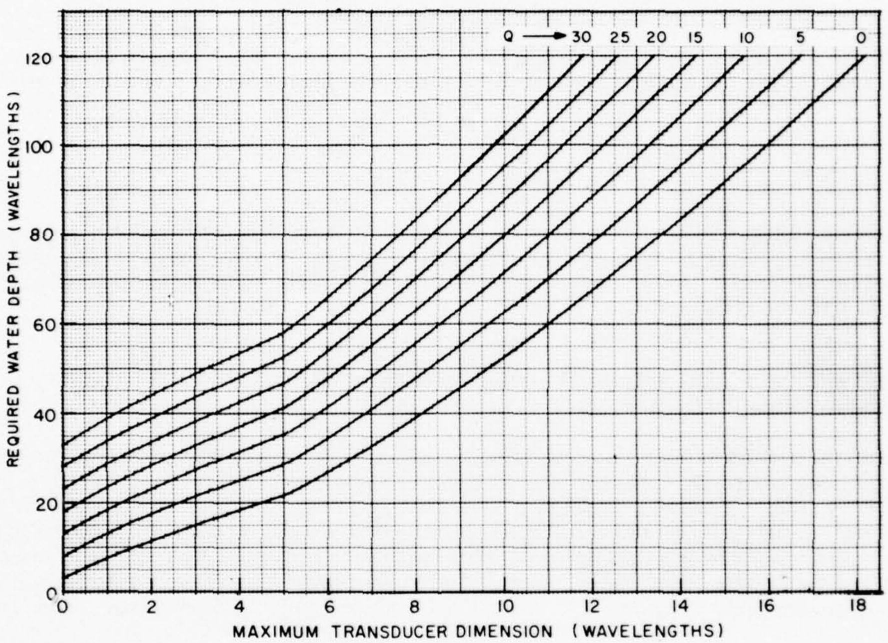

Fig. 3. Minimum water depth required for calibration measurements using pulse technique

A radically different technique, with limited though very useful application to small hydrophones, is the so-called noise method, in which the calibration tank is flooded with wide-band noise and the frequency response of the hydrophone is obtained by sweeping through the desired range of frequencies with a bandpass filter. The calibration is obtained by comparing the results against similar data taken on a reference hydrophone. This method is used at NADC for calibrating sonobuoy hydrophones over a range of frequencies extending down to 200 cps. It is rapid, inexpensive, repeatable to within about ±1 db, and is, in fact, the only economically feasible method of calibrating large quantities of cheap hydrophones. Experience has shown that a remarkably uniform sound field can be generated, the variation being less than 0.5 db over a range of 10 in. The noise method is of course subject to error in the vicinity of resonant frequencies, and its application is therefore limited to relatively low-Q devices.

An example of a transducer which would require either deep-water or anechoic boundaries for calibration would be a 20-ft line hydrophone operating at approximately 1.0 kc, having an omnidirectional pattern in the plane normal to the line axis. Far-field criteria call for a test path of

$$R = d^2/\lambda = 400/5 = 80 \text{ ft}$$

$$R = 5d = 100 \text{ ft}.$$

The line is 4λ in length, giving it a beamwidth of 13 degrees. At most calibration facilities it is conventional and convenient to make pattern measurements by rotating the transducer about a vertical axis. In this case, provided side-wall reflection can be neglected, sensitivity measurements may be made with the line in a vertical position, and the pattern in the plane normal to the line can be measured with little trouble. For measurement of the pattern in the plane of the line, the problem of surface and bottom reflections must be considered. For a test-path distance of 100 ft, the total water depth should be 1000 ft in order to insure 20-db attenuation of reflected signals.

A technique mentioned earlier may be used in this situation to reduce the depth requirements. For measurement of the pattern in the plane of the line, the other transducer used in the calibration can be chosen to be a line transducer and can be oriented so that its axis is normal to the axis of the line being calibrated. As an example, take the case of the two lines being of equal length. The minimum test distance will be increased by a factor of four:

$$R = (d_1 + d_2)^2/\lambda = 320 \text{ ft}$$

$$R = 5(d_1 + d_2) = 200 \text{ ft}.$$

If the distance is taken to be 320 ft, then the first null of the pattern for the vertical transducer will strike the reflecting boundary at the midway point when the transducer is approximately 40 ft from the boundary. A total water depth in this case would be 80 ft, considerably less than the 1000 ft obtained previously.

APPLICATION OF NEAR-FIELD CALIBRATION TECHNIQUES TO TRANSDUCER CALIBRATION

As was mentioned earlier, most underwater sound transducers are employed operationally under conditions where the transmission path places the other terminal in the Fraunhofer region, or far field. It follows that it is desirable to have far-field calibration data for the transducers. In the past the sizes of transducers and the operating frequencies have been such that this type of calibration could be performed in relatively small tanks and test ponds. The trend toward lower-frequency sonar has resulted in the use of transducers too large to allow far-field measurements to be made in many of the existing tank facilities, test ponds, and lakes.

One solution, or partial solution, to this problem is to make measurements of the acoustic pressure field in the Fresnel region or nearby field, and use these data to compute the far-field characteristics. This technique has been used for many years in the electromagnetic-wave-antenna field, and in recent years it has been investigated rather extensively by DRL and USRL (Refs. 7-19). The methods developed by these two laboratories are basically different, and each will be described briefly.

In general, the DRL method uses a small probe transducer to measure the amplitude and phase of the pressure field over a surface which encloses the directivity patterns, source levels, receiver sensitivity, and efficiency. The technique has been applied with success to line, circular piston, and cylindrical transducers. Measurements may be made in comparatively small tanks, which have highly reflective walls, by using a pulse technique. The amplitude and phase of the projected signal are measured on the leading edge of the pulse, after steady-state conditions have been reached, but prior to the arrival of any reflected energy from the walls of the tank. As an example, the AN/SQS-4 transducer has been calibrated accurately in a tank having dimensions only 2.9 times the linear size of the transducer.

The USRL method involves the use of a large plane array of small sources to form a plane wave. Within a restricted volume near the array the wave is essentially plane, and within this volume the transducer to be calibrated is placed. The calibration procedure is then identical with conventional far-field methods. The measured pattern is equivalent to a far-field pattern, and no further computation is required.

Each of the two methods has its advantages and disadvantages. The USRL method obtains the desired pattern and sensitivity measurement without further recourse to computation. The

DRL method, on the other hand, provides detailed information on the individual elements and thus may be more useful for location of faults and malfunctions. The USRL method requires the use of a transducer array larger than the transducer under tests. (USRL is conducting studies to determine the optimum type and size of the array.) The DRL method requires only a single small transducer or line, but it requires that the probe be scanned over an area covering the unit being calibrated. The DRL method permits calculation of the pattern in any desired plane, while the USRL method is limited to measurement of the pattern in the plane normal to the axis of rotation of the transducer under test. The volumes and test distances required for both methods are much smaller than are needed for conventional far-field calibrations. The volume needed for the DRL method is somewhat less than that needed for the USRL method. Both methods have been shown to give satisfactory results on the transducers tested to date. There are, however, instances in which it would appear that the techniques would not yield calibrations equivalent to far-field measurements. One possible example is a transducer which is producing cavitation at a distance from the transducer which is greater than the distance from the transducer to the calibration probe or array. The near-field techniques assume a homogeneous medium, and this condition is not met for a cavitating transducer.

The techniques of near-field calibration are in an early developmental and research stage. It is likely that as more work is done the areas of application will be extended. For instance, in the DRL method an assumption is made concerning the expression for the normal component of the pressure gradient ($\partial p/\partial n = ikp$). This assumption has been shown to be valid for a number of specific transducers. The reason for expressing the gradient in terms of the pressure is that suitable devices for measuring the gradient directly are not available. If and when such instrumentation is developed, the application of the technique will be extended considerably. The current state of development of near-field techniques indicates that this method could be put to use in the near future as a means for calibrating and testing specific types of production transducers in Navy shipyards.

A second application of near-field techniques would appear to be to make preliminary tests of transducers prior to making final far-field tests and calibrations. This action should reduce sharply the load on deep-water facilities, since many defects, malfunctions, and shortcomings should become apparent at an early stage. Manufacturers and others without complete calibration facilities should make use of the near-field technique prior to sending units to Navy test stations for calibration. It should be noted that in some instances near-field measuring made with the transducer in air can serve to determine whether the transducer is operating properly and to locate faults.

Recently DRL has instrumented a 20 × 24 ft redwood tank for the calibration of the AN/SQS-23 and similar transducers using the near-field technique. USRL is also working actively in this area. Work is being conducted at Stanford Research Institute and American University on other techniques for making near-field calibrations in small tanks. The reverberation method is one of the techniques being investigated.

Acoustic measurements in high-pressure tanks would appear to be an area in which near-field measurements would be particularly useful, since the available volume is so limited.

The near-field technique has several inherent advantages as a means for calibration. Since the transmission path is extremely short, the measurements are essentially independent of water conditions such as thermoclines and stratification. Experience has shown near-field data to be highly reproduceable. When the measurements are made in an enclosed tank the usual advantages of a tank are obtained. These include (a) low ambient, (b) isothermal water, (c) isolation from other noise sources and calibration systems, and (d) practicality of indoor installations. Potentially, the near-field technique may be adaptable for in-place calibration of sonar transducers.

TECHNIQUES FOR HIGH-PRESSURE TESTS

The need for high-pressure testing and calibration of transducers is apparent. An increasing number of surface ships will be employing VDS sonar with the transducer at depths to 500 ft or more. The operating depth of submarines is steadily increasing. Special submersibles, such as TRIESTE, ALUMINAUT, etc., will probe the deepest parts of the ocean.

There is a rapidly growing need for operating acoustic devices at great depths. All of these uses require calibration and testing of transducers under high hydrostatic pressure. Several solutions are possible; none will completely solve the problem, but all are required.

High-pressure tanks, some for acoustic measurements, are a necessity for the overall program. The USRL-proposed 40-ft anechoic spherical tank should permit testing of transducers, or components of transducers, with dimensions up to 10 ft at simulated depths of perhaps 10,000 ft. The volume of this tank will be considerably greater than that of existing tanks. However, even this facility will be limited by the size of transducers that can be tested.

Deep-lake facilities are probably the only practical answer for the testing of complete large sonar transducers under free-field and far-field conditions. Lake Pend Oreille has a depth in excess of 1000 ft. Lake Seneca and other eastern lakes have depths of over 500 ft. While these depths certainly are less than deep ocean depths, they are sufficient for the testing and calibration of VDS sonars, most submarine sonars, most sonobuoys, and most R and D work.

Special deep-diving submarines such as the NEL TRIESTE can be used as a sonar transducer calibration platform for going to any desired depth. The weight limitation is severe, being about 1000 lb total (including instrumentation) for TRIESTE, and the usage factor may well be low. However, this particular device does have unique capabilities and, of considerable importance, it is already in existence. It is recognized that the total work load of this submarine is not sufficient to handle any large part of the total need.

The proposed AUTEC calibration facility will provide essential capability for in-place calibration of transducers installed in ships and submarines. In addition, the stable platform (FORDS) will provide a range of pressure testing at depths in excess of those available elsewhere. It, too, will be limited in its capacity by interference, by bad weather, and by remoteness from the users. No doubt it will be necessary to restrict its use to those tasks which cannot be handled elsewhere.

OPEN TANKS AND ARTIFICIAL LAKES

It should be noted that many transducers can be calibrated (near-field pulse) in comparatively small and inexpensive tanks. For example, the AN/SQS-4 transducer can be calibrated, using the near-field-pulse method, in a 7 × 8 ft tank which costs less than $200. The discussion which follows considers some of the types of tanks and their general costs.

Galvanized iron is used for tanks up to 5000-gallon capacity. The cost of these tanks per unit volume decreases somewhat with size and is about 10 cents per gallon in the 2000-gallon range.

Steel plate is used to construct tanks of all sizes up to 2,500,000 gallons, and perhaps larger. Again, the cost per unit volume decreases with increasing size. In the 100,000-gallon size the cost is about 9 cents per gallon, including erection and cover. The cover may amount to as much as 20 percent of the cost.

Concrete is favored for the construction of very large tanks. In one example a 10,000,000-gallon concrete tank cost approximately 4 cents per gallon (i.e., $400,000 exclusive of excavation and engineering).

Redwood stave construction is commonly used in tanks of capacities up to 1,000,000 gallons. The height of these tanks is normally about 20 ft, although stave splicing can be employed for greater heights at an increase in cost per unit volume. The erected cost of a redwood tank is similar to that of a steel tank of equal capacity. The price for a 500,000-gallon redwood tank is about 7 cents per gallon, while for a 60,000-gallon tank (20 ft high × 24 ft diameter) the cost is about 11 cents per gallon.

In some instances artificial ponds or lakes can be formed at a cost less than for a tank of comparable size. Shallow pools in soil can be dug by a bulldozer to depths up to 20 ft at a cost of approximately 20 cents per cubic yard. Clamshell excavation for moderate depths runs at

approximately 40 cents per cubic yard. For depths in the order of 100 ft, the lower depths might cost several times this figure. Hard strata will increase the cost, of course.

AUTOMATION IN TRANSDUCER CALIBRATION

A greater use of automation in data collection and processing offers several advantages. It should result in higher accuracy, precision, and reliability. It should also result in faster data processing and should require fewer people for this phase of the work. There is a need for a well-designed general system which, through selection of component assemblies, would be suitable for all sizes of facilities, large and small, and which would have sufficient flexibility to permit expansion and modification as techniques are improved and modified. Digital systems, because of the inherent flexibility, are preferable in general to analogue devices.

Automation in the equipment for handling transducers also has much to offer. The growing demand for calibration of transducers at great depths indicates the desirability of developing improved equipment for positioning the transducer at the desired depth. The "bicycle chain" transducer column being installed by NEL at Lake Pend Oreille is a unique solution that has much to offer. The type of articulated strut employed on early ASW VDS sonars and present VDS minehunting sonars may be suitable as a transducer column of rapidly variable length. Transducer supports employing flexible cables are entirely practical. The rotation mechanism, together with a reference direction sensor, would be attached to the lower end of the cable with the control and position repeaters located on the surface platform. A "new-generation" type of column is needed if the deep-water facilities are to be used efficiently.

In the development and expansion of floating facilities, anchored remotely from shore, serious consideration should be given to the design of equipment for picking up the transducer on shore and placing it in position on the platform for calibration. Much valuable facility time can be lost due to inefficiency in the arrangements for handling large, heavy transducers.

CALIBRATION FOR SMALL, LOW-FREQUENCY HYDROPHONES

It is often entirely practical to calibrate small, low-frequency hydrophones by means of secondary calibration "pots." These are employed to some extent at the present time, but probably not to the extent they should be. Basically, the calibrator consists of a stiff-walled vessel containing a low-frequency acoustic driver, monitoring calibrated transducer, thermometer, pressure gauge, and opening to which the hydrophone to be tested is clamped. The interior volume is made as small as possible. The interior is pumped up to the static pressure desired. The entire assembly can be placed in a controlled-temperature box. This type of calibrator is inexpensive, small, simple to use, and has sufficient accuracy for most applications.

FACILITY REQUIREMENTS FOR THE CALIBRATION OF MINEHUNTING SONAR TRANSDUCERS

Minehunting sonars which have been developed during the past 15 years have operated at frequencies from 35 kc to 1500 kc. Transducer dimensions have been as large as 100 in., but more typical values are in the order of 36 in. or smaller. Hydrophone beamwidths range from 5 degrees to 0.1 degree. Source levels have ranged up to +135 db for pulse sonars and +110 db for continuous transmission.

Generally, it is desirable to obtain directivity patterns, source level, and hydrophone sensitivity for the transducer in the far field.

The criterion of Eq. (1) is usually the most difficult one to meet. For example, a 36-in. hydrophone, operating at 100 kc, requires a test distance of approximately 180 ft. Many calibration facilities do not have a test range this great. For a classification sonar operating at 350 kc, with a 36-in. hydrophone, the far-field distance is approximately 650 ft. Such a transducer, however, would seldom be used at such a range; that is, it would usually be operated in

the near field, and it would be desirable to obtain patterns for the ranges at which it would be used. It should also be noted that transducers may be calibrated for separations as small as 0.5 $d^2\lambda$ and corrected to far-field conditions with considerable confidence.

In summary, it is believed that a test distance of approximately 100 yards would be sufficient for the calibration of most minehunting sonar transducers. A water depth of at least 60 ft is desirable. By positioning the transducer at mid-depth and with a test distance of 300 ft, the direct path signal can be resolved from the boundary reflected signals for pulses as long as 1.0 millisec. Further, the vertical-plane directivity is usually such as to eliminate boundary reflections. Isovelocity water for the transmission path is necessary for the calibration of the transducers at high frequencies. It should be noted that special recording equipment is required for the accurate measurement of beam patterns having beamwidths in the order of 0.1 degree.

It is entirely feasible to calibrate minehunting sonar transducers by means of near-field measurements. At Defense Research Laboratory this technique is used to locate malfunctions in transducers but has not yet been used to compute directivity patterns and source levels at frequencies above 150 kc.

The calibration of high-frequency transducers at DRL is done at the Lake Travis Test Station. Water depth under the barge is 60 ft and increases to 200 ft at the deepest part of the lake. Test distances are adequate for all of the transducers encountered to date. One test path is between the barge and a subsurface tower in the lake. The separation is 450 ft. On the barge test paths up to 100 ft are available.

CALIBRATION OF TRANSDUCERS FOR ACOUSTIC MINE MECHANISM

Acoustic mine mechanisms are of two general types, active and passive. Passive units usually operate in the low sonic frequency range, while active units generally operate in the middle or high kilocycle range. Requirements for calibration facilities are not very difficult to meet. The high-frequency active units are of necessity small, and calibration can be accomplished with ease in most tanks. These units are generally pulse-transmission types. Passive units are generally small omnidirectional units. These transducers can usually be calibrated in a small-volume pressure chamber or calibration pot in which the fluid volume is made as small as possible. Straight calibration is not difficult, but mine mechanisms are used often on the ocean bottom or near reflecting surfaces of the ocean bottom and top. In situ calibration is more difficult but can be achieved.

Generally, existing facilities at Naval Ordnance Laboratory and Defense Research Laboratory are adequate to accommodate the calibration of acoustic mine mechanism transducers.

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CHAPTER 3

EXISTING FACILITIES

The information presented in this chapter includes data from a wide variety of transducer calibration facilities that are owned and operated by the Navy, by Navy-supported, nonprofit institutions, and by private contractors. The basic data have been obtained by direct solicitation, and considerable effort has been extended for the sake of completeness. If any omissions have occurred, they probably represent newly acquired facilities of private contractors who are just beginning to venture into transducer and undersea-warfare research and development.

Before looking closely at the characteristics of the various facilities, one may find it informative to consider their geographical distribution. Figure 4 is a United States map showing the locations of the various facilities. The legend on the figure identifies each facility with its cognizant activity. The rather notable clustering of facilities which occurs in the northeastern part of the United States reflects the high concentration of transducer research, development, and industrial support centers in this region. Of the 24 facilities listed, however, only six are operated by Navy in-house and contract laboratories for research and development purposes.

In the summaries to follow, the calibration facilities have been categorized according to two different schemes. The first scheme subdivides the facilities according to size. Table 1 presents information on those facilities that employ oceans, ocean inlets, and large lakes. Specifically, this table includes only those facilities having useful water depths of 200 ft or more. The volume of water at each of these facility sites is greater than 10^{10} cu ft.

Table 2 gives similar information on facilities employing small lakes, rivers, bays, ponds, and pools. This table includes those facilities that are too small to fall in the first category but that are large enough to have an associated water volume of more than 10^4 cu ft. In order for this table to be as up to date as possible, the NEL Transducer Evaluation Center, TRANSDEC, which is now under construction, has been included, and the NEL Sweetwater Calibration Station, which will be closed following the completion of TRANSDEC, has been omitted.

Table 3 presents data on those facilities which have an associated water volume of less than 10^4 cu ft. As the reader will note, some of the chambers listed have volumes of only a few cubic feet. Special attention is invited to this table, because it includes, with the exception of the TRIESTE, all of the high-pressure (1000 psi) acoustic calibration facilities that are currently available. The pressure and frequency capabilities of these chambers are given in the right-hand column.

The next method used in categorizing these facilities is according to controlling activity and use. In order to make these divisions meaningful in terms of the ultimate potential of the various facilities, water depth has been introduced as a distribution parameter. Figure 5a is a histogram showing the distribution according to water depth of the U.S. Navy and Navy-controlled calibration facilities which are used for transducer research and development. The reader should note that the depth intervals, rather than being linear, increase successively by factors of two. The significance of each interval's being twice the size of its predecessor is

NOTE - The collection of submitted original material, both data and pictures, is too large and bulky to be included in this publication. However, the material is on file in the Office of Naval Research, Code 468 (Acoustic Programs), and may be consulted and inspected there.

that the facilities falling within a particular interval have essentially a two-fold greater low-frequency calibration potential than those falling in the next smaller interval.

Also, in the compilations shown in this and the following figures, two or more separate barges or pier houses on the same body of water have been counted as two or more facilities. On the other hand, the TRIESTE, which is already being used in transducer-calibration work at depths far greater than 1280 ft, is not included in the histogram.

Figure 5b is a similar histogram for existing U.S. Navy evaluation and test facilities. Neither of the two deeper facilities is adequately equipped or instrumented for transducer research and development, nor were they ever intended for this purpose.

Figure 5c is a histogram giving the distribution as a function of water depth of contractor-owned facilities. The large number of facilities falling within the 10 to 20 ft depth increment reflects the contractors' needs for production test facilities. Although the histogram gives no clue, correspondence received in connection with the solicitation for information indicates that many of these facilities are new and have been procured by contractors who are just entering the field.

The Navy's best and most versatile deep-water calibration facility is located in Idaho on Lake Pend Oreille. The upper left portion of Fig. 6 shows the position of the lake with respect to the borders of Idaho. The remainder of the figure is an enlargement of the circled portion of the lake. The position of the village of Bayview and of the David Taylor Model Basin Field Station are shown, along with the present position of the NEL Calibration Station barge. The 600 and 900 ft depth contours are also presented for reference purposes.

Although Lake Pend Oreille is geographically poorly located with respect to the centers of transducer research, development, and industrial support, it has many desirable features to offer from the transducer-calibration point of view. It is some 30 miles long and three to five miles wide. The depth over most of its extent is greater than 1000 ft, typically being greater than 500 ft within 100 ft of shore. The lake is accessible and open throughout the year. It can be reached by either highway or railroad, and assemblies weighing some 50 tons can be lowered directly from railroad cars on the trestle near Sand Point to barges on the lake below.

Except near the surface the temperature of the lake remains constant at 39°F winter and summer, with the surface water dropping to this temperature in midwinter. This thermal structure makes it possible to avoid the effects of thermoclines and to remove the discrepancies caused by temperature variations from comparative measurements made over long time periods and at different times. Its low ambient noise level (-43 db referred to 1 microbar at 32 cps with a slope of -6 db/octave increase in frequency) makes it very suitable even for large-scale, low-frequency receiving-array calibrations.

The NEL Pend Oreille Calibration Station now operates a double shift during the five mid-year months, and a single shift during the remainder of the year. A large single moored barge houses the principal calibration facilities. Primary power of 560 kva is supplied via shore-connected underwater power cables, and transport barges are used for ferrying transducers and associated equipment to and from the moored barge.

Lake Pend Oreille has ample room to accommodate a second barge and in fact plans for a special-purpose mobile barge specifically designed to meet the amplifier-transducer development and engineering-evaluation requirements for the echo-ranging source now being developed by NEL, for the FACSS system, are currently being evolved by NEL. Inasmuch as this barge would be necessitated by and used exclusively for the FACSS system, the costs would be borne by that project and would not come from major-facilities construction money.

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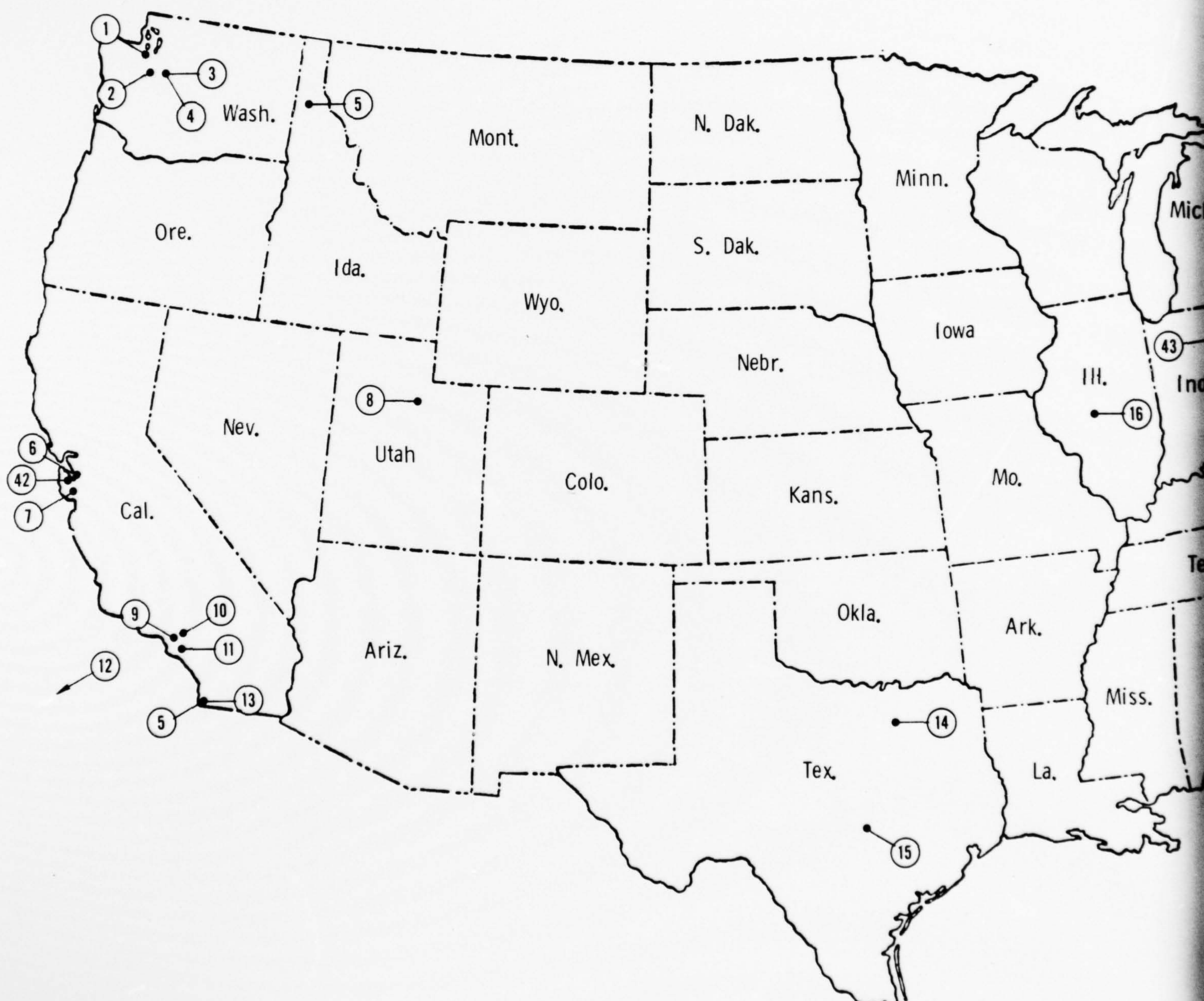
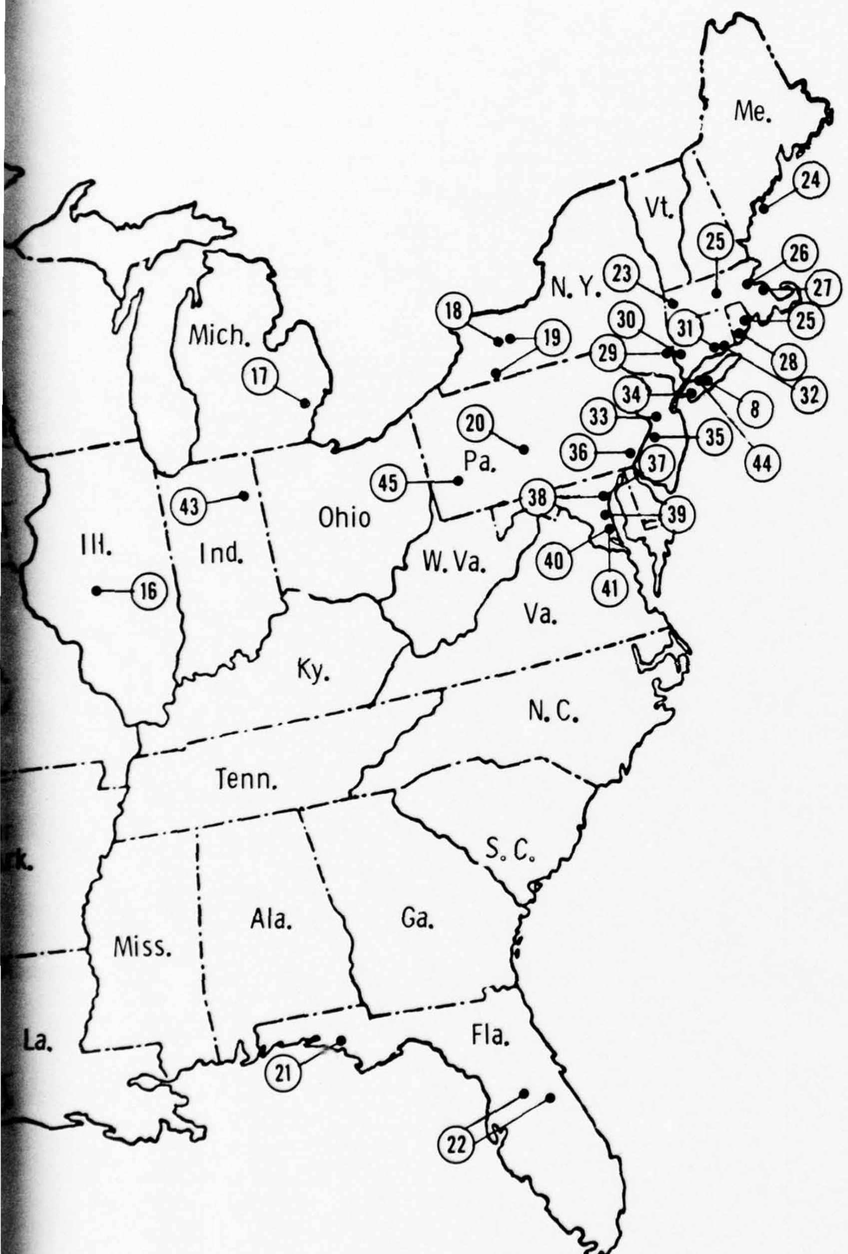
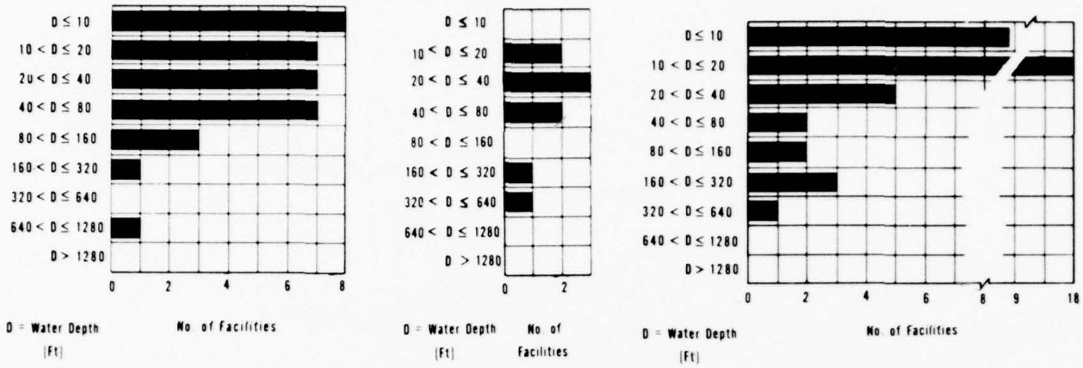


Fig. 4. Locations of U.S. underwater transdu



ACTIVITY	LOCATION OF FACILITY
1. U. S. Naval Torpedo Station	Keyport, Washington
2. Puget Sound Naval Shipyard	Carr Inlet, Washington
3. Applied Physics Laboratory University of Washington	Seattle, Washington
4. Seattle Development Laboratory Minneapolis Honeywell Regulator Co.	Lake Washington, Seattle, Wash.
5. U. S. Navy Electronics Laboratory	San Diego, California Lake Pend Oreille, Idaho
6. Mare Island Naval Shipyard	Vallejo, California
7. Stanford Research Institute	Menlo Park, California
8. Edo Corp.	College Point, New York
9. Bendix-Pacific	North Hollywood, California
10. U. S. Naval Ordnance Test Station	Morris Dam, Pasadena, Calif.
11. Hughes Aircraft Co.	Fullerton, California
12. Pearl Harbor Naval Shipyard	Oahu, Hawaii
13. Research Manufacturing Co.	San Diego, California
14. Texas Instruments Inc.	Dallas, Texas
15. Defense Research Laboratory University of Texas	Lake Travis, Austin, Texas
16. Sangamo Electric Co.	Springfield, Illinois
17. Research Laboratories Division Bendix Corporation	Southfield, Michigan
18. General Electric Co, Syracuse Division	Lake Cayuga, New York
19. General Dynamics/Electronics	Lake Seneca, New York Rochester, New York
20. Ordnance Research Laboratory	Black Moshannon, State Park, Pa. University Park, Pennsylvania
21. U. S. Navy Mine Defense Laboratory	Panama City, Florida
22. U. S. Navy Underwater Sound Reference Laboratory	Orlando, Florida Leesburg, Florida
23. Sprague Electric Co.	North Adams, Massachusetts
24. U. S. Naval Sonobuoy Test Facility (BUWEPS/NADC)	Gulf of Maine
25. Raytheon Co. Submarine Signal Operations	Portsmouth, Rhode Island Southboro, Massachusetts
26. Boston Naval Shipyard	Boston, Massachusetts
27. Massa Division, Cohu Electronics, Inc.	Hingham, Massachusetts
28. U. S. Naval Underwater Ordnance Station	Newport, Rhode Island
29. Daystrom Electric Co.	Poughkeepsie, New York
30. General Instrument Corp.	Woodbury, Connecticut
31. U. S. Navy Underwater Sound Laboratory	Dodge Pond, Niantic, Connecticut
32. Electric Boat Division, General Dynamics	Waterford, Connecticut
33. Gulton Industries, Inc.	Metuchen, New Jersey
34. Grumman Aircraft Co.	Bethpage, New York
35. RCA Laboratories	Princeton, New Jersey
36. U. S. Naval Air Development Center	Johnsville, Pennsylvania Oreland, Pennsylvania
37. Martin Aircraft Co.	Middle River, Maryland
38. Ordnance Division Westinghouse Defense Center	Baltimore, Maryland
39. U. S. Naval Ordnance Laboratory	Triadelphia Lake, Brighton, Md.
40. Chesapeake Instrument Corp.	Shadyside, Maryland
41. U. S. Naval Research Laboratory	Washington, D. C.
42. Dalmo Victor Company	Belmont, California
43. The Magnavox Company	Fort Wayne, Indiana
44. Hazeltine Corporation	Greenlawn, New York
45. Westinghouse Research Laboratories	Pittsburgh, Pennsylvania

underwater transducer calibration facilities



a. U.S. Navy and Navy-controlled R and D facilities

b. U.S. Navy evaluation and test facilities

c. Contractor-owned R and D facilities

Fig. 5. Distribution of transducer calibration facilities according to water depth

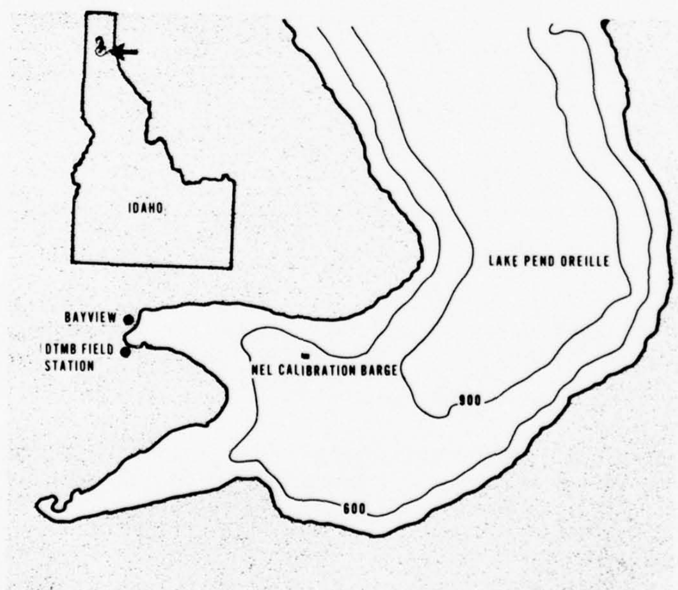


Fig. 6. Calibration facilities at Lake Pend Oreille, Idaho. The outline map of Idaho shows the position of the lake with respect to the state borders. The remainder of the figure is an enlargement of the circled portion of the lake. The indicated depths are in feet.

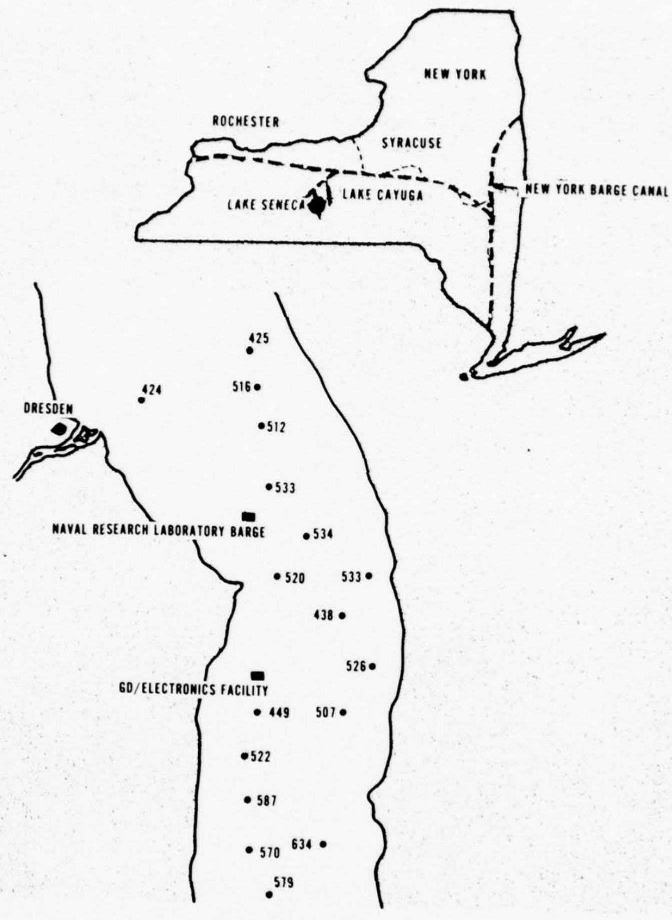


Fig. 7. Calibration facilities at Lake Seneca, New York. The upper portion shows the lake with respect to the boundaries of New York and the New York Barge Canal. The lower portion is an enlarged outline of part of the lake. The indicated depths are in feet.

Among other lakes in the United States, the one best suited for low-frequency calibration work is Lake Seneca, located in the Finger Lake region of New York. The upper portion of Fig. 7 shows the position of the lake with respect to the boundaries of New York and with respect to the New York Barge Canal. The lower portion of the figure, an enlarged outline of the lake, shows the location of the existing General Dynamics/Electronics Calibration Facility and the location of the new recommended Navy-owned facility. This lake is about 35 miles long and about 3 miles wide at its widest point. The maximum water depth is approximately 600 ft, and it has a clay and fine-sand bottom.

Geographically, the lake is well situated with respect to much of the transducer development and construction activity in the United States. Barge canals connect the lake with the Atlantic Ocean via the Hudson River, and with Lake Ontario and the St. Lawrence Seaway. Although the canals may be closed to traffic three to four months per year, the facilities on the lake can be operational 12 months per year because of its sheltered position and its accessibility by highway, air, and rail.

A resumé of facilities would not be complete without some example showing the increasing demands being made on existing facilities. For this purpose, three additional figures taken from the records of the U.S. Navy Underwater Sound Reference Laboratory are included. Figure 8 gives the number of high-quality calibration transducers that USRL has had on loan over the past 3-1/2-year period to other calibration facilities. Worthy of special note is the fact that the rate of issue in the past year has jumped from 65 to 95 units per year. Figure 9 shows the number of normal calibrations performed by USRL each year over the past seven years. The trend is typical of all Navy-owned R and D facilities, and it shows that the work-load has essentially doubled in the last three years.

Lastly, Fig. 10 shows that the demand for calibrations at pressures and temperatures far removed from typical near-surface ambients has risen fourfold in the last four years.

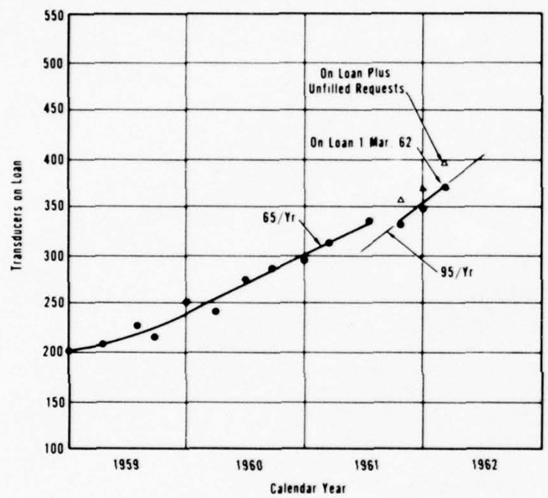
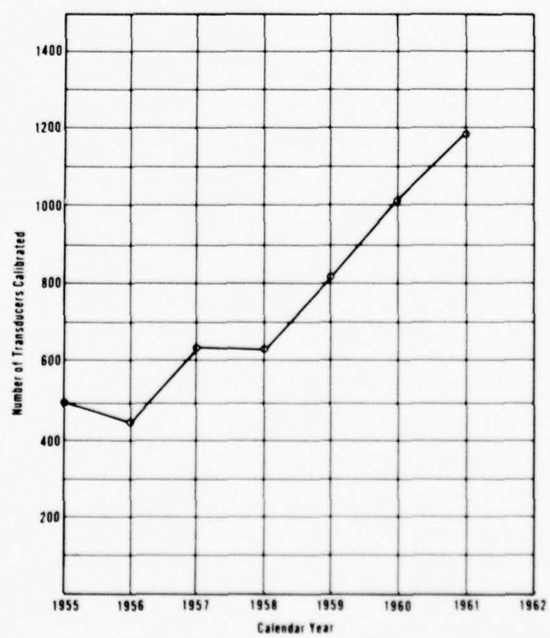


Fig. 8. Secondary standard transducers on loan by USRL to other Navy activities and contractors

Fig. 9. Number of transducers calibrated under ambient conditions at USRL each year over the past seven years



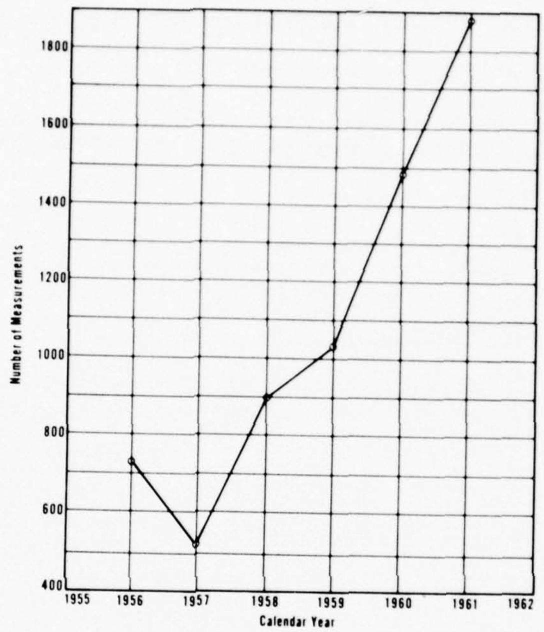


Fig. 10. Number of calibrations at controlled pressures and temperatures at USRL since 1956

Table 1
Underwater Sound Calibration Facilities Employing Oceans and Large Lakes and Inlets (Depth $\geq$ 200 ft; Water Vol. > 10^{10} ft^3)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities or Limitations
Eastern U.S.A.							
1. Naval Sonobuoy Test Facility, BuWeps/NADC Johnsville, Pa.	Gulf of Maine near Bath, Me.	Test and eval. of sample lots of production sonobuoys	Depth: 200-400 ft	Sonobuoys (<1 ton)	100 watts	Depends entirely on work load	This facility, which is currently operated by Volcaline Co. of America under BuWeps contract, is not used and is not suitable for transducer R&D.
2. General Dynamics/Electronics Rochester, N.Y.	Lake Seneca, N.Y.	General transducer calibration	3 × 35 miles max. depth: 600 ft	35 tons plus 5 and 10 ton capacity monorails	40 kw modular amplifier under construction	Five, not including data reduction personnel	Pier facilities plus self-propelled barge. (200 kw of primary electrical power are available on the barge.)
3. General Electric Heavy Military Electronics Dept. Syracuse, N.Y.	Lake Cayuga, N.Y.	General transducer calibration	1 × 35 miles 200 ft deep at barge. Max. depth: 400 ft	Seven tons with limited 30-ton capability	20 kw continuous, 35 kw pulse	Up to ten as required, including two for data reduction	Barge is a converted, self-powered LCU. Signal power rating is for frequency range 20 cps to 50 kc.
4. General Electric Heavy Military Electronics Dept. Syracuse, N.Y.	Skaneateles or other nearby lake	Instrumentation testing	Varies with lake. Skaneateles is approx. 1 mi × 10 mi × 200 ft	100 lb	200 watts	Five	This is an amphibious houseboat which can be instrumented in the laboratory and driven to the general test site.
Central U.S.A.							
1. Defense Research Laboratory University of Texas Austin, Texas	Lake Travis 17 miles from Austin	General-purpose transducer research and development	50 × 0.25 mi 200 ft deep	Two tons	250 watts	As required from staff of 15	Can measure extremely narrow directivity patterns. Steady state limits: 400 cps to 2.5 Mc. Utilizes floating barges on Lake Travis.
Western U.S.A.							
1. Navy Electronics Laboratory San Diego, Calif.	Lake Pend Oreille Bayview, Idaho	General transducer calibration, especially low frequency units	(3 to 5) × 30 mi 1000 ft deep	Ten tons (50-ton transport under construction)	200 kw (10 to 20 kw modules) (primary power 560 kva)	Five	Can make steady-state calibration as low as 20 cps without need for standing wave corrections.
2. Navy Electronics Laboratory San Diego, Calif.	Bathyscaph TRIESTE San Diego, Calif.	Calibration of transducers at deep submergence	Open ocean to deepest depths	One ton including mounting and rotational fixtures	Primary 60 cps AC power: 1kva	Two	Maximum of 4 dives per month. Maximum horizontal separation of transducers: 60 ft.
3. Puget Sound Naval Shipyard Bremerton, Wash.	Carr Inlet, Wash.	"In situ" calibration of ship and submarine mounted sonar	2 × 10 mi 360 ft deep	Test instrumentation only	100 watts	16	This facility is not suitable for transducer R&D. Even the transducers employed in Carr Inlet are developed and calibrated by other activities.
4. Minneapolis Honeywell Reg. Co. Seattle Development Lab. Seattle, Wash.	Lake Washington and Puget Sound, Wash.	Transducer development and calibration	Depths: 200 ft at Lake Washington. 600 ft at Puget Sound	1-1/2 tons to 700 ft 5 tons to shallow depths	2 kva (60 kva primary power)	12	Self-propelled barge for operation in Lake Washington and Puget Sound.

Table 2
Underwater Calibration Facilities Employing Small Lakes, Rivers, Bays, Ponds, and Pools
(Water Volume > 10^4 ft^3)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities, Limitations, and Remarks
Eastern U.S.A. 1. Naval Air Development Center Johnsville, Pa.	Flooded quarry at Oreland, Pa.	Small transducer calibration	450 × 900 ft, 65 ft deep	50 lb	20 watts	Assigned as required	Water surface is frozen over approx. two months per year. Facility is only partially developed. Barge will replace raft float when funds are allocated.
2. Navy Mine Defense Laboratory Panama City, Fla.	Panama City, Fla.	Transducer and equipment calibration pool	150 ft dia., 20 ft deep	Two tons	200 watts (100 kw primary power)	Two	Pool is partially spanned by pier with 40 ft long center well and overhead monorail.
	Bay or Gulf of Mexico	Sonar system development and tests	Water depth at mooring sites: approx. 33 ft	Three tons	Depends on project requirements. (30 kw primary power)	Up to six when operating	These facilities employ transportable acoustic calibration instrumentation systems. Instrumentation is modified as required to meet project needs. Most work is pointed toward the development and engineering evaluation of mine countermeasure systems rather than of transducers.
	"Stage I" Gulf of Mexico adjacent to Panama City	Enclosed building on ocean tower for general purpose sonar test and measurement use	Water depth: 105 ft Average wave height: 2 ft	Four tons	Depends on project requirements. (320 kw primary power)	Three when operating	
	"Stage II" Gulf of Mexico adjacent to Panama City	Same as above	Water depth: 60 ft Average wave height: 2 ft	Portable weight handling equipment only	Depends on project requirements. (220 kw primary power)	Up to six when operating	
	East Dock on Bay, Panama City	General purpose sonar test and development use	Water depth: 20 ft	Three-ton monorail	(88 kw primary power)	Three when operating	
	Ammunition dock, Panama City	Same as above	Water depth: 10 ft	Portable weight-handling equipment only	(48 kw primary power)	Up to six when operating	
3. Naval Ordnance Laboratory White Oak, Md.	Barge on Tridelphia Lake Brighton, Md.	Transducer research and development	3 mi × 1/4 mi × 60 ft deep	One ton	1 kw (20 kva primary power)	Two	A high-frequency calibration capability extending to 2 Mc with special instrumentation for target strength and correlation studies.

Table 2 (continued)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities, Limitations, and Remarks
4. Naval Research Laboratory Washington, D.C.	YFNX-13 Sound barge on Potomac River, Alexandria, Va.	Transducer research and development	250 yd wide × 25 ft deep. Length essentially unlimited.	Six tons	10 kw (175 kva primary power)	Five	Calibration capability limited to frequency range between 2 and 150 kc.
5. Navy Underwater Ordnance Sta. Newport, R.I.	Calibration pool, NUOS, Newport, R.I.	Torpedo transducer and torpedo research and development	30 ft diameter × 15 ft deep	Two tons	50 watts (4 kva primary power)	Four	Facility includes two catwalks that can be operated at half tank depth and provisions for operating torpedo propulsion systems under load. Pool is filled with sea water.
6. Navy Underwater Sound Laboratory New London, Conn.	Three barges on Dodge Pond, Niantic, Conn.	Research and development on transducers, arrays, and sonar systems	1760 × 880 ft, 48 ft deep	Maximum capability of respective barges: 25, 6, and 1/2 ton.	40 kw (300 kva primary power)	Ten	Barges are connected to shore by pontoon causeway. Water is mechanically stirred to break up undesirable thermal structures. Maximum well to well separation: 84 ft.
7. Navy Underwater Sound Reference Laboratory Orlando, Fla.	Floating barge on spring at Leesburg, Fla.	Transducer research and development	375 × 325 ft, 120 ft effective depth. (175 ft maximum depth)	500 lb (5-ton capability proposed)	20 watts battery operated. No 60-cps a.c. interference.	Zero to three, as required	Low ambient noise level (-43 db re 1 microbar at 100 cps with -5 db/octave slope). This partially developed facility is weight and power limited.
	Four pier facilities on lake at Orlando, Fla.	Calibration of secondary standard transducers and transducer research and development	870 × 850 ft, 30 ft deep	Respective Capabilities Five tons 1-1/2 tons 1-1/2 tons 1-1/2 tons	 10 kw 200 watts 10 watts 5 watts (100 kva primary power)	 Two Two Two Two	Facility has special instrumentation for measuring characteristics of sonar domes for frequencies as low as 5 kc.
8. Boston Naval Shipyard Boston, Mass.	Boston Harbor, Boston, Mass.	Transducer and sonar system maintenance repair	2 mi long × 1000 ft wide × 45 ft deep	15 tons	30 kw	Six	System designed especially for calibration of AN/SQS-4 transducers. Uses floating barge (YFNX-15). (Another barge, YFN-288 is also being modified for transducer calibration use.)
			2 mi long × 220 ft wide × 28 ft deep	100 lb	60 watts	Six	Sound barge and hydrophone calibration facility.

Table 2 (continued)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities, Limitations, and Remarks
9. Ordnance Research Laboratory University Park, Pa.	Piling-supported building on lake in Black Moshannon State Park, Pa.	Transducer and acoustic torpedo research and development	2.5 mi × 1000 ft, 14 ft deep	Two tons	10 watts (75 kva primary power)	Five	Upper frequency limit on current instrumentation 150 kc. Ambient noise spectrum level -50 db re 1 microbar at 1 kc; slope -6 db/octave.
10. Bendix Corporation Southfield Detroit, Mich.	Bendix's Fire Water Reservoir, Southfield, Mich.	Underwater acoustic research	48 × 36 ft, 12 ft deep	1-1/2 tons	Varied to meet requirements	Up to seven depending on requirements	Used in support of Bendix's Research and Development program on low-frequency projectors.
11. Chesapeake Instrument Corp. Shadyside, Md.	Parish Creek Chesapeake Bay	Private, general purpose, low-level calibration	0.1 × 1 mi, 18 ft deep at pier	Two tons	100 watts	Four	2 cps to 150 kc, pulse or steady state. Water depth at proposed pier location 35 ft. Ambient noise level less than sea state 2.
12. Daystrom Electric Poughkeepsie, New York	Flooded quarry at Poughkeepsie, N.Y.	Hydrophone and source development for sonobuoy systems	1800 × 900 ft, 135 ft average depth, maximum depth 150 ft	Three tons	20 watts and explosive sources	Six	Can measure directivity patterns and source levels of explosives. Floating rafts are used to obtain winch-controlled separations up to 500 ft. Maximum separation 1200 ft.
13. Edo Corporation College Point Long Island, New York	Floating barge on East River and Flushing-Bay, College Point, Long Island, N.Y.	Engineering and production testing of sonar transducers and systems	Depth: 12 to 22 ft	12 tons	7 kw-cw, 27 kw at 30 percent duty cycle	Six	Seven wells on 32 × 110 ft floating barge. Columns in all wells are trainable. Instrumentation frequency limits: 100 cps to 250 kc.
14. Electric Boat Division of General Dynamics New London, Conn.	Booth Quarry, Waterford, Conn.	Transducer calibration and radiated noise studies	700 × 250 ft, 60-80 ft deep	Two tons	50 watts	Up to 48, including up to 30 in data reduction	Have test barge designed to simulate quarter section of submarine hull.
15. General Dynamics/Electronics Rochester, New York	Rochester, N.Y.	Acoustic test facility for underwater experimentation and transducer research and development	48 ft diameter × 30 ft deep	2.5 tons	250 watts	Four	Underwater lights and viewing ports in addition to acoustic instrumentation. Lowest normal operating frequency 2 kc.
16. Gulton Industries Metuchen, New Jersey	Ganoque Lake, Ontario, Canada	Self-propelled barge on a deep-water lake		Barge apparently designed for "roll on-roll off" instrumentation. No additional information was submitted.			

Table 2 (continued)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities, Limitations, and Remarks
17. The Magnavox Company Fort Wayne, Indiana	Mobile sound measurement laboratory used on Lakes James, Tippecanoe, and Oswego in Indiana	Transducer research and development (facility is principally used for hydrophone calibration)	Clear Lake: 1 mi × 2 mi × 108 ft deep Lake James: 1-1/2 mi × 4 mi × 84 ft deep Tippecanoe: 1 mi × 3 mi × 125 ft deep	200 lb	35 watts (2.5 kva primary power)	Four	Facility utilizes a self-propelled catamaran barge 8 ft wide × 20 ft long, and a barge trailer. Frequency limits or current instrumentation: 20 to 20,000 cps.
18. Martin Marietta Corporation Martin Company Division Middle River, Md.	Floating barge on Bay Inlet at Middle River, Md.	In-house transducer research and development	700 ft wide, 23 ft deep	1000 lb	200 watts (20 kva primary power)	Ten	Barge is used as operating platform. Electronic system is ashore. Facility is being augmented by a 54-ft-long ASW test vessel having 2 kw of signal power and 6500 lb lifting capacity.
19. Massa Division of Cohu Electronics Hingham, Mass.	Hingham, Mass.	Transducer engineering and production tests	100 ft × 60 ft × 14 ft deep	1/2 ton	3 kw (40 kva primary power)	14	Test laboratory constructed over center of pool.
20. Raytheon Company Submarine Signal Operation, ASW Center Portsmouth, R.I.	Pontoon barge on Sudbury Reservoir, Southboro, Mass.	Transducer development and production testing	1200 × 1000 ft, 50 ft deep	One ton	7.5 kw (100 kva primary power)	Five	Upper frequency limit of present instrumentation 500 kc.
	Cement pool at ASW Center, Portsmouth, R.I.	Transducer research and development	L shaped 40 and 35 ft legs, 20 ft wide, 20 to 24 ft deep	Two tons	10 kw (45 kva primary power)	Five	Frequency limits of present instrumentation 25 cps to 150 kc.
21. Westinghouse Defense Center Baltimore, Maryland	Baltimore 3, Md.	Transducer research and development	205 × 175 ft, 25 ft deep	One ton	120 watts to 50 kc, 6 watts to 2 Mc (75 kva primary power)	Three plus personnel required for data reduction	Floating barge on artificial lake. Instrumentation limits 50 cps to 2 Mc.
22. Westinghouse Research Laboratories Pittsburgh, Pennsylvania	Churchill Borough Pittsburgh 35, Pa.	High frequency (0.5 to 2 Mc transducer research and development	60 × 90 ft with 4 ft depth	Estimated to be less than 100 lb	10 kw pulse power (10 kw primary power)	Two	Can measure directivity patterns in the 0.5 to 2 Mc frequency range for beam widths as narrow as 0.1 degree. Instrumentation is mounted in trailer laboratory.
Western U.S.A. 1. Mare Island Naval Shipyard Vallego, California	Vallejo, California	Transducer maintenance and repair	60 ft diameter × 24 ft deep	12 tons with portable crane services available	30 kw (50 kva primary power)	Four or more as required	Facility is especially equipped for testing high-power, scanning transducers under omni and RDT modes of operation. Instrumentation limits 1 to 30 kc.

Table 2 (continued)

Activity	Facility Location	Type or Purpose	Approx. Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities, Limitations, and Remarks
2. Naval Ordnance Test Station China Lake, California	Morris Dam Pasadena, California	Underwater ordnance and supporting transducer R & D	L shaped, 2000 ft and 5000 ft legs, 500 ft wide, 110 ft deep	Estimated weight-handling capacity for transducers 1000 lb	Depends upon instrumentation and test requirements.		Instrumentation for low-level transducer calibrations over a 20-cps to 150-kc range. Facility includes one main barge and three smaller ones.
3. Naval Torpedo Station Keyport, Washington	Bay at Keyport, Washington	Transducer tests and repair	3 × 1 mi, 25 ft minimum depth	One ton	20 watts (150 kva primary power)	Three	Electronic instrumentation limits 40 cps to 300 kc. Barge is on salt water.
4. Navy Electronics Laboratory San Diego, California	Transducer Development and Evaluation Center (TRANSDEC), NEL, San Diego, Calif.	Geometrically controlled reflection, anechoic pool for general purpose transducer R & D	300 × 200 ft, 38 ft deep	Two tons	10 kw (55 kva primary power)	Four	TRANSDEC, which will be fully operational by May 1963, will replace the NEL Sweetwater Calibration Station, which has been omitted from the tabulation.
5. Pearl Harbor Naval Shipyard Pearl Harbor, Hawaii	Bldg. 1234, PHNSY, Pearl Harbor, Hawaii	Transducer maintenance and repair	275 × 250 ft, 60 ft deep	Ten tons with portable crain services available	10 kw (36 kva primary power)	Seven	Facility is instrumented for measuring effects of domes on transducer beam patterns. Facility is located at end of pier in an inlet open to the sea.
6. Bendix-Pacific Division North Hollywood, California	Sylmar, California (near Los Angeles)	Transducer and sonar system R & D	75 × 35 ft, 35 ft deep	Ten tons	25 kw maximum (75 kva primary power)	Up to seven	2.5 kc to 100 kc pulse system using unlined concrete tank.
7. Dalmo Victor Company Belmont, California	Belmont, California	Tests on AN/AQS-2 transducers and AN/PQS-1 sonars	95 × 15 ft, 15 ft deep	Five tons	200 watts (70 kw primary power)	Two	Electronic instrumentation limits 20 cps to 100 kc. Wall reflection loss 11 db at 15 kc; 23 db at 50 kc.
8. Hughes Aircraft Company Fullerton, California	Underseas Warfare Dept. Fullerton, California	Transducer R & D	30 ft diameter × 20 ft deep	Not stated	200 watts now available. (50 kva primary power)	Two	Redwood tank now under construction. Primarily for near-field work.
9. Research Manufacturing Corp. San Diego, California	Floating barge on Quivera Basin, Mission Bay, San Diego, California	Transducer research and development	1000 × 200 ft, 21 ft deep	500 lb	1200 watts, 0.5 to 20 kc; 100 watts, 20 to 200 kc	Two	Low frequency, steady state limit 5 kc, with a pulse capability to 1 kc.

Table 3
Small Acoustic Calibration Pools and Tanks (Volume < 10^4 ft^3)

Activity	Type of Tank	Approximate Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities or Limitations
Eastern U.S.A.						
1. Naval Air Development Center Johnsville, Pennsylvania	Fully enclosed, circular, wooden tank	20 ft dia. × 12 ft deep	500 lb	50 watts	Two	Pulse-type semiautomatic frequency response and pattern measuring equipment. Instrumentation 5-150 kc. Max. pulse length 5 millisec.
	Fully enclosed, circular, wooden tank	30 ft dia. × 12 ft deep	500 lb	50 watts	Four	Instrumentation similar to above, except that f.equency range extends from 5-500 kc.
2. Navy Mine Defense Laboratory Panama City, Florida	Water-filled acoustic pressure calibrator. Steel construction.	30 ft long × 1 ft dia.	25 lb	60 watts	As required	Used for point-by-point response calibrations over frequency range of 2 through 500 cps.
3. Navy Underwater Sound Reference Laboratory Orlando, Florida	Steel, anechoic high-pressure acoustic calibration tank	26 ft long × 8-1/3 ft dia.	1000 lb	50 kw	Three	Pressure range 0-1000 psig. Temperature range 3°-40°C. Frequency range 5-150 kc pulsed. Maximum transducer size 30 in. dia. Maximum separation 8 ft.
	High-pressure acoustic tank made from gun barrel liner	55 ft long × 15 in. dia.	100 lb	50 watts	One	Pressure range 0-8500 psig. Frequency range 100-1500 cps.
	High-ambient-pressure acoustic pressure calibrator	60 in. long × 11 in. dia.	100 lb	Sound pressure level approx. 1000 microbars over operating band.	Two	Designed for two-projector null-absolute calibrations on acoustically stiff transducers. Frequency range 0.3-1000 cps. Pressure range 0-1000 psig.
	High-ambient-pressure acoustic tank	55 ft long × 1-3/4 ft dia.	---	50 watts	---	Pressure range 0-8500 psig. Frequency range 100-1500 cps.
	High-ambient-pressure acoustic pressure calibrator. (Constructed from 16-in. Mk 13 naval shell.)	28 in. long × 9 in. dia.	---	---	---	Pressure range 0-1500 psig. Frequency range 20-500 cps.
4. Ordnance Research Laboratory University Park, Pennsylvania	Fully enclosed concrete tank with anechoic lining	12 ft × 4-1/2 ft × 8 ft deep	2000 lb	---	Approx. three when tank is in use	All surfaces including top are lined with anechoic wedges. Tank is very anechoic above 20 kc but is usable at frequencies as low as 20 kc.
5. Chesapeake Instrument Corporation Shadyside, Maryland	Wooden test tank for random noise calibration	15 ft dia. × 15 ft deep	---	60-watt noise generator	Up to six	System employs noise-calibration technique. Frequency coverage 1-6 kc in 11 steps.
6. Edo Corporation College Point Long Island, New York	Circular wooden tank for production testing	73 in. dia. × 87 in. deep	2000 lb	30 watts	Two	Frequency range 5-200 kc.
	Circular wooden tank for production testing	114 in. dia. × 67 in. deep	2000 lb	60 watts	Two	Frequency range 5-200 kc

Note - Dashes indicate that information was not supplied.

Table 3 (continued)

Activity	Type of Tank	Approximate Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities or Limitations
7. General Electric Heavy Military Electronics Department Syracuse, New York	High-ambient-pressure hydrophone calibrator	1 ft dia. × 4 ft deep	---	---	As required	Pressure range 0-10,000 psig. Frequency range 2-600 cps. System employs lead metaniobate expander source and calibrated hydrophone.
	Circular wooden tank for production testing	26 ft dia. × 8 ft deep	1000 lb	60 and 200 watts	Up to six	Pulse type calibration equipment. Frequency range 5-150 kc.
	Rectangular concrete tank (Farrell Road Plant)	30 ft × 30 ft × 7 ft deep	1000 lb	60, 200 and 1500 watts	Up to six	Pulse-type calibration equipment. Frequency range 5-500 kc.
8. General Instrument Corporation Woodbury, Connecticut	Rectangular pool with sound-absorbent bottom	20 ft × 15 ft × min. depth of 9 ft	Six tons	---	Five	Recommended for transducer impedance measurement work used for acceptance tests on AN/SQS-4 transducers
9. Grumman Aircraft Engineering Corp. Bethpage, New York	Circular cedar tank for instrumentation testing	15 ft dia. × 10 ft deep	50 lb	60 watts	Up to five	Used for model studies and velocity meter work.
10. Hazeltine Corporation Greenlawn, New York	Indoor cylindrical wooden tank	20 ft dia. × 12 ft deep	One ton	90 watts	Six	Frequency range of pulse-type instrumentation 1-100 kc.
11. The Magnavox Company Fort Wayne, Indiana	Indoor cylindrical concrete tank	20 ft dia. × 20 ft deep	1000 lb	55 watts	Four	Frequency range of pulse-type instrumentation 1-10 kc.
12. Martin Marietta Corporation Olmstead Air Force Base, Pennsylvania	High-ambient-pressure acoustic calibrator	---	---	---	---	Pressure range 0-10,000 psig. Upper frequency limit 600 cps.
13. Westinghouse Research Laboratories Pittsburgh, Pennsylvania	Indoor rectangular polyvinyl-lined wooden tank	5 ft × 15 ft × 5 ft deep	---	1 kw peak	As required	High-frequency calibration facility for transducer and acoustic lens R & D. Frequency range 500-2000 kc.
Central U.S.A. 1. Defense Research Laboratory University of Texas Austin, Texas	Circular redwood tank	24 ft dia. × 20 ft deep	15 tons	4 kw	Two	Primarily for near-field work in the 3.5-14 kc band.
	Mason-type anechoic tank	4 ft × 2 ft × 3 ft deep	Small	Small	One	Anechoic tank used for impedance measurements.
	Two identical circular steel tanks	7 ft dia. × 8 ft deep	Three tons	4 kw	Two	Used principally for near-field studies on large transducers.
	Rectangular glass tank	5 ft × 2.5 ft × 3 ft deep	Small	Small	Two	Used for model studies at frequencies above 50 kc.
2. Sangamo Electric Company Springfield, Ohio	Rectangular semi-anechoic concrete tank	20 ft × 20 ft × 20 ft	One ton	4 kw	Up to 12	Thirty percent of walls are covered with Goodrich Saper sound-absorbing rubber. Used for pulse-type calibration over frequency range of 2-60 kc.

Table 3 (continued)

Activity	Type of Tank	Approximate Dimensions	Wt. Handling Capability	Signal Power	Number of Personnel	Special Capabilities or Limitations
3. Texas Instruments Incorporated Dallas, Texas	Indoor rectangular concrete tank	30 ft × 15 ft × 14 ft deep	---	300 watts	Three	Facility employs a gated-pulse calibration system. Upper frequency limit of instrumentation 150 kc.
Western U.S.A.						
1. Mare Island Naval Shipyard Vallejo, California	Two identical circular tanks enclosed in same building	16 ft dia. × 18 ft deep	One ton	50 watts	---	One tank is equipped for small-transducer calibration using the pulse technique. The other uses white noise and a wave analyzer for the measurement of hydrophone response.
2. Navy Electronics Laboratory San Diego 52, California	Indoor rectangular metal tank with absorptive lining and viewing port holes along sides and ends	6 ft × 10 ft × 6 ft deep	Small	Varies with test. Usually less than 20 watts	Up to three as required	Sides and floor of tank lined with Goodrich Type SOAB-1 absorptive rubber. Used for model studies at frequencies above 100 kc.
3. Pearl Harbor Naval Shipyard Pearl Harbor, Hawaii	Rectangular concrete anechoic tank (part of transducer test and repair facility)	16 ft × 16 ft × 14 ft deep	One ton	10 watts	Up to seven as required	Isothermal water. Natural annual temperature excursions 72°-76°F. Frequency range of instrumentation 1-200 kc.
4. Applied Physics Laboratory University of Washington Seattle, Washington	Circular wooden tank	7 ft dia. × 40 in. deep	200 lb	500 watts	Four	Gated pulse system. Frequency range 30-1000 kc.
5. Bendix Pacific North Hollywood, California	Dual concrete pool with inverter-vee bottom	25 ft × 15 ft × 14-1/2 ft deep	1000 lb	10 kw	Up to ten as required	Gated pulse system. Frequency range 5-500 kc.
	Indoor rectangular concrete tank	33 ft × 18 ft × 16 ft deep	1000 lb	10 kw max.	Up to ten as required	Gated pulse calibration system. Frequency range 5-500 kc.
6. Electro Ceramics, Incorporated Salt Lake City, Utah	Indoor cylindrical wooden tank	16 ft dia. × 11 ft deep	---	60 watts	Five	Instrumentation frequency range 0.5-600 kc.
7. Hughes Aircraft Company Fullerton, California	Indoor rectangular tank	10-1/2 ft × 5 ft × 5-1/2 ft deep	---	200 watts	Adjusted to meet requirements	Gated pulse instrumentation. Frequency range of pulse system 5-50 kc.
8. Stanford Research Institute Palo Alto, California	Circular steel tank	8 ft dia. × 12 ft deep	1000 lb	100 watts	Up to seven as required	Present instrumentation employs reverberation tank technique for measuring total acoustic power output. Frequency range 20 cps, 40 kc.

CHAPTER 4

THE PROBLEM AREAS

TECHNICAL REQUIREMENTS

A discussion of the problem areas affecting the calibration of acoustic transducers logically begins with a consideration of the technical requirements imposed by the transducers themselves. Equipment characteristics such as weight, size, power, frequency, and environmental factors such as operating depth establish the requirements which the calibration facilities must meet if adequate tests are to be run.

Tables giving equipment parameters, operating depths, required facility water depth, and current status of the principal transducers in several of the major categories listed in Chapter 1 will be published separately at higher classification.

An examination of transducer characteristics reveals two significant trends which are of paramount importance in assessing the transducer-calibration-facility picture. First is the trend toward larger, heavier, lower-frequency, higher-powered transducers. For example, the SQS-4, SQS-23, and SQS-26 transducers weigh 2 to 5, 10, and 30 tons, respectively. The weight of the early Lorad transducer was seven tons; the current model weighs 19 tons, and projected future models will weigh over 90 tons. Three-quarters of the modules of the Artemis transducer in MISSION CAPISTRANO are now assembled in place, and the whole will weigh 325 tons when complete. Similarly, input peak-power requirements have risen from a few kilowatts into the megawatt range. For most of these transducers the water depths required for cw calibration measurements are of the order of several hundreds of feet. Even though much of the test work may be done in smaller facilities using some of the special techniques described in Chapter 2, deep-water facilities such as Lake Pend Oreille are required for complete evaluation of the transducers. The trend clearly indicates that the need for such facilities will continue to increase.

The second trend is toward deeper operating depths. Variable-depth sonars are being developed for surface ships. Submarine depths are continually being increased. Helicopter-dipped sonar cables are being extended to 500 ft. A standard depth of 1500 ft has recently been specified for sonobuoy hydrophones. A requirement for 1500 ft now exists for torpedo transducers. The Artemis projector is to be placed at a depth of 1200 ft, and the depth of the receiving array will range from 4000 to 7000 ft. And, finally, depths in excess of 12,000 ft are required for bottom-mounted surveillance transducers and for equipments such as Deep Julie hydrophones and explosive charges and the Air Transportable Sonar buoy, which are being developed to make use of the reliable acoustic path.

Calibrations of high-powered submarine and VDS transducers must be made at sufficient depth to avoid cavitation. Deep lakes such as Pend Oreille and Seneca should be satisfactory. For the smaller, lower-powered airborne transducers, tests in pressure tanks should suffice to establish the effect of pressure variation and enable routine calibrations to be carried out at shallower depths.

However, the most significant implication of the trend toward great operating depths is the need for high-pressure test facilities. Although ultimately calibrations of very deep transducers must be carried out in the ocean, either at AUTEC or in deeper water, it is utterly impractical to go to sea for the many tests required for research, development, prototype evaluation, and production acceptance. Adequate pressure tanks readily accessible to laboratories and

manufacturers are essential if excessive delays in the accumulation of knowledge and the development of adequate hardware are to be avoided. The need for pressure facilities is already acute, and the trend clearly shows that unless prompt action is taken it will become steadily worse.

LIMITATIONS OF AVAILABLE FACILITIES

In assessing the Navy's needs for transducer calibration facilities, one must take into account other factors in addition to the technical requirements. While it is obvious that facilities must be available which have adequate weight-handling capacity, water volume, power, frequency range, hydrostatic pressure, etc., for the transducers to be calibrated, other factors such as availability, workload capacity, and adequate staffing are equally important. Analysis of the current demands on calibration facilities leads to a division of the problem into five categories, according to the purpose of the tests:

1. Standards and techniques
2. Research and development by in-house and nonprofit contract laboratories
3. Other contractor development
4. Prototype and preproduction testing
5. Production acceptance and maintenance testing.

The normal course of development of a sonar system begins with research and continues through the development of a prototype model which must be thoroughly evaluated, the construction and acceptance of preproduction samples, routine acceptance tests of production items, and finally maintenance and overhaul tests of fleet equipment. In addition, facilities are required for the calibration and maintenance of standards and the development and improvement of calibration techniques. Since the nature of the measurements, the methods employed, the characteristics and desired location of facilities, and the workload all depend strongly upon the purpose of the tests, it will be convenient to discuss each of the categories separately. Because of the shortage of available facilities, however, a complex situation has developed in which facilities designed for one purpose are in some cases being pressed into service for other purposes as well. This is particularly true of certain R and D facilities which are being required to devote a large percentage of their use to prototype and preproduction testing.

Standards and Techniques

All meaningful measurements rely on the existence and use of standards. Standards are carefully calibrated and are designed to hold their calibrations for a reasonably long time when used as intended. Recalibration is desirable periodically or whenever inaccuracy is suspected. The U.S. Navy Underwater Sound Reference Laboratory has as one of its primary responsibilities the design and calibration of all standards. USRL has discharged this responsibility in a highly satisfactory manner. Some concern is felt that other demands on their limited personnel may infringe on a continuing adequate output of standards. This must not be permitted.

The development of techniques for use in taking measurements is not so completely centered in one activity as is the provision of standards. USRL should and does play an important role and is presently taking the lead among in-house laboratories in the development of near-field techniques for making transducer measurements. Other laboratories continue to solve specific problems in which they are involved.

Near-field techniques are receiving attention also from a number of contractors. The contribution of the Defense Research Laboratory is particularly noted. This area of study needs continued support because of its potentially broad application and the economy of space which it offers.

The area of standards and techniques is not regarded as offering any serious problems if adequate priority is assigned at USRL and sufficient personnel are provided there.

Research and Development by In-house and Nonprofit Contract Laboratories

Research and development are the first steps in meeting fleet needs. Data must be taken, problems must be solved, improvements must be made, and new types of transducers must be evolved to provide knowledge which can be tapped to meet fleet requirements. Without research and development fleet problems would be increased, and the cures would be more costly to achieve.

The scientist, in making measurements, cannot be satisfied with a few statements and rules of operation. He wishes to know why his advice behaves as it does, how it will behave under a wide variety of parameter variations, and how long it will operate properly. He seeks confirmation and further development of theory, evaluation of fatigue and life, and establishment of design limitations. The facility requirements for research-and-development measurements are far more difficult and subtle than for routine tests of production items, because of the need for maximum versatility and the demand for the elimination of all variables except the one under study.

The current level of research-and-development activity is difficult to specify in any terms which will be uniformly informative for all laboratories, since the calibration of a unit may vary from a simple determination of response of a single element at a few frequencies to the testing of complicated arrays of many interacting transducers. In addition, there are facility scheduling problems, since in the course of development all progress may be held back pending the determination of a particular characteristic. This leads to difficulty in evaluating the efficiency of operation of a facility or of the needs for additional capability.

<u>Information Obtained from Laboratories</u> - In an attempt to establish the current status, a questionnaire was sent to 18 Navy in-house and nonprofit contract laboratories. Of the 17 replies received, three organizations (DTMB, OCEANO, WHOI) reported that they have no facilities of their own but rely on those of other laboratories. All but two (Lamont, NEL) of the remaining 14 laboratories reported inadequacies of one sort or another. The bulk of the difficulties can be divided basically into three categories:

1. Excessive workload
2. Technical requirements beyond the capabilities of the existing installation
3. Need for improved instrumentation.

In the first of these categories, the principal problem is the overcrowding of a facility designed for laboratory research and development through the assignment of prototype and preproduction testing work for production contractors. Three of the laboratories – USL, USRL, NADC – are particularly affected. This problem will be discussed in a later paragraph. Most of the other laboratories reported that their facilities have adequate capacity for their workload, although in several instances their manpower levels are too low to handle the workload expeditiously.

A much more serious problem is that of the inadequacy of existing facilities with respect to the technical requirements imposed by current trends in transducer development. It is apparent that the current needs of research and development are not at present adequately met in these three areas:

1. Testing of large, low-frequency transducers
2. Nonacoustic testing at high pressure
3. Acoustic-performance testing at high pressure.

All of these arise from the need to produce acoustic systems, active and passive, to detect submarines at greater ranges and under wider varieties of environmental conditions. This requirement has already led to the necessity for lower frequency, higher power, larger dimensions, and deeper operating depths, and the trends already begun and already exceeding our test facility capabilities will continue. It is to be expected that as long as the facilities are inadequate, the research to provide the actual hardware components will continue to lag behind the achievements which our knowledge of sound propagation and signal processing indicate may be possible.

Open-Water Facilities - A major requirement reported by several laboratories is the need for greater water depth than is presently available in order to support research on large, low-frequency transmitting and receiving arrays. At the present time the only suitable Navy facility is the calibration station at Lake Pend Oreille, Idaho, where water depths in excess of 1000 ft are available. This facility is operated by NEL and is used almost exclusively for R and D measurements. However, in spite of repeated expansions and improvements, the workload at Pend Oreille has steadily risen to the point where two-shift operation is now in progress, for five months of the year. In their replies to the questionnaires, almost all of the laboratories which have need of the Pend Oreille facility reported difficulty with scheduling problems and delays, and the east-coast laboratories complained of inaccessibility. It is abundantly clear that Pend Oreille is not capable by itself of satisfying all of the Navy's deep-water calibration needs. Both of the two laboratories (NRL and USL) having the greatest need for deep water report that their R and D programs are severely hampered by the lack of such a facility. The NRL calibration barge is located on the Potomac River on 25 ft of water and is limited to measurements at frequencies above 10 kc. Calibrations of low-frequency arrays are currently being carried out at sea, but this procedure is wasteful of both money and time and has caused unacceptable delays in urgent projects. In some instances it has been necessary to forego tests which, if they could have been made, would have prevented subsequent equipment failures. The situation at USL is scarcely better, since the water depth at the Dodge Pond facility is only 50 ft. A deep-water inland facility readily accessible to the east-coast laboratories is urgently needed to expedite the Navy's low frequency acoustics program.

The situation with regard to smaller local open-water facilities to handle calibrations not requiring deep water appears to be considerably less critical. Most of the laboratories have facilities adequate to take care of their shallow-water needs, or have arrangements with other laboratories. There are a few exceptions, however, which deserve special mention.

The USL facility, although adequate to handle the laboratory's own shallow-water R and D work, is overburdened with prototype and preproduction testing for BuShips contractors.

The Navy Oceanographic Office expects to procure a number of transducers per year as components of acoustic equipment used for ocean-survey and environmental-research purposes. It is necessary to conduct acceptance tests on these transducers and to calibrate them periodically during their service life. Since the Navy Oceanographic Office has no calibration facility of its own, acceptance tests are currently being run at USRL and NOL, and long delays are being encountered. Periodic recalibrations have not been made, due to lack of facilities.

It is not clear at present just how large their test and calibration requirements will become. Therefore, whether OCEANO should undertake to develop and operate a full-scale calibration facility of their own is an open question at this time. As the program needs develop, a determination of this question will be made.

NADC has a requirement for an outdoor facility for calibrations and other tests which cannot be run in its laboratory calibration tanks. A suitable site has been found at Oreland, Pennsylvania, about seven miles from the laboratory. This is a flooded quarry whose dimensions are approximately 400 × 900 ft and whose depth is about 65 ft. The property at the quarry site has been leased, and plans for the development of the facility have been drawn up and submitted to BuWeps. The need for full development of this facility is becoming increasingly acute as a result of the increased emphasis which is being placed on the development of linear hydrophone arrays for sonobuoys and directive charges for explosive sound sources.

In order to acquire a deep-water capability and to expand its present workload capacity, USRL is developing a facility at Leesburg, Florida, approximately 50 miles from Orlando. The water at this site is isothermal and has a depth of 170 ft, a considerable improvement over the present 30-ft depth at the Orlando facility. During the past year USRL has leased the property and has equipped it with a small waterborne structure suitable only for very light devices. Further development of this site will be required to enable USRL to handle its steadily increasing workload.

The NRL Potomac River barge has been moved to a place where the water is less polluted than off the NRL dock. NRL's ability to hold the present site is not assured. Furthermore, the weight-handling capacity is severely limited. A superior arrangement would be to provide NRL with an indoor anechoic tank as part of a central test facility in their existing building, A59. This building is already equipped with adequate traveling-crane facilities.

Pressure Tanks - In the pressure-testing category, over one-third of the 17 reporting laboratories indicated unsatisfied requirements for testing components at pressures of several thousand psi to insure proper operation of these units in the ocean. It is essential that these simple hydrostatic tests of the mechanical structures, watertight seals, etc., be conducted at convenient locations, preferably at the developing laboratory, and that where possible the facilities be given the additional capability of testing the acoustic response of small units at low frequency (wavelength large compared with element dimensions).

In particular, two laboratories reported specific plans for high-pressure tanks. NRL is planning a cylindrical tank having an inside diameter of 8 ft, and capable of pressures up to 5000 psi. This tank has recently been budgeted. USL has made plans for a tank 4 ft in diameter, 12 ft long, and capable of pressures up to 15,000 psi, but funding has not been obtained.

Most of the laboratories having a high-pressure requirement reported also a need for performing calibrations under high pressure. For systems whose dimensions are large compared with the wavelength, this requirement is difficult to meet. The only laboratory with any appreciable capability in this area is USRL, which has a tank 8 ft in diameter by 26 long, capable of pressures up to 1000 psi. This tank has neither the volume nor the pressure capability nor the workload capacity to satisfy all the demands made upon it. Recognizing the problem, USRL is making plans for an anechoic spherical tank 40 ft in diameter which it is hoped will be capable of pressures in excess of 3000 psi. Sound absorption will be accomplished by wedges to be installed inside the sphere. However, in order to be effective over a frequency range extending down to 500 cps, it is anticipated that the wedges will restrict the available working space to a diameter of about 20 ft. The proposal is currently undergoing a feasibility study by Southwest Research Institute, San Antonio, Texas. The requirement for the procurement of the tank is now carried in the ONR MilCon Program for FY64. This tank, when procured, will represent the only significant capability for high pressure acoustic measurements on large components, short of actual tests in the ocean. It is urgently needed.

It is apparent, however, that the proposed USRL 40-ft tank will not satisfy all the requirements for high-pressure acoustic measurements, either with respect to technical considerations (size, frequency, pressure) or with respect to workload. To satisfy the workload requirements it will be necessary to procure additional tanks, probably more modest than that of USRL. It is desirable that these tanks be located at the major R and D laboratories in order that they may be used most expeditiously.

There does not appear to be any simple solution to the problem raised by technical requirements in excess of the capabilities of the USRL tank. Two alternate approaches seem feasible. One is to make measurements directly in the ocean. The bathyscaphe TRIESTE is currently being used for such measurements, but this at best is a makeshift arrangement, since the TRIESTE cannot carry a load of more than 1000 pounds, including both transducer and measuring equipment, and is limited to a maximum of four dives per month. The bulk of the high-pressure acoustic measurements at sea will have to be made at facilities such as AUTEC and will require the development of a suitable stable platform. The study currently in progress at NRL in the development of such a platform is therefore of great importance.

A second approach is to observe the variation in performance with pressure over some restricted range and extrapolate to determine behavior at greater values. The usefulness of the USRL tank can be extended in this way. Measurements made in deep lakes, such as Pend Oreille and Seneca, although more limited as to pressure range, can also provide a valuable basis for extrapolation.

Improved Instrumentation - Several laboratories reported a need for automated instrumentation to speed up the acquisition and analysis of calibration data. Manual point-by-point calibrations are very time consuming and subject to human error. A significant improvement in capability, both in quality and quantity, can be achieved by the development of an automated calibration system using modern sampling and computation techniques, including compensation for the frequency response of the measuring system. The development of such a system would have wide applicability and would be particularly valuable in relieving the pressure on overloaded facilities.

Other Contractor Development

The problems faced by contractors with development contracts are similar to those of in-house laboratories. Most contractors appear to have adequate tank facilities for tests not requiring large water volumes or high pressures. Some do not, however, and in addition there has been an increasing workload of tests for which small, open tanks are not adequate. For this work the contractors have received appreciable assistance from the Navy in-house laboratories, especially USRL. Although these laboratories will continue to cooperate to the best of their ability, it is evident that in the future the contractors must prepare themselves to satisfy a greater percentage of their own requirements. Several manufacturers have already recognized the problem and have taken steps to provide their own facilities. Examples are General Dynamics/Electronics on Lake Seneca, General Electric on Lake Cayuga, and Minneapolis-Honeywell with a mobile platform operating in Puget Sound. This trend should be encouraged in order to avoid overloading the facilities in in-house laboratories.

Prototype and Preproduction Testing

Testing prototype and preproduction models for the purpose of determining the extent of their adequacy and specifying shortcomings which require correction prior to going into production is an arduous task, especially when a transducer system of the size and weight of the SQS-23 or SQS-26 is involved and when models are submitted by several manufacturers. Yet the Bureaus have established no overall plan for the conduct of prototype and preproduction tests. Tests are run wherever available facilities can be found. The bulk of the work for BuShips is done at USL, the remainder at USRL. Most sonobuoy transducers are calibrated at NADC, and most torpedo transducers are calibrated at USRL. Airborne dipped sonar transducers are calibrated at both of these latter laboratories.

The result of the current practice has been the overloading of laboratory facilities to the point where the laboratories' own R and D programs are suffering. The most flagrant example is at USL, whose Dodge Pond facility recently has been used 75 percent of the time for tests of contractors' items. While USL certainly has serious concern with some of these tests, much of the work serves to deprive the laboratory of valuable facility time needed for its own R and D work. USL estimates that it can tolerate a maximum of 25 percent of its Dodge Pond facility time for contractors' tests and urgently recommends that the present workload be cut down to that figure as soon as possible.

A similar problem exists at USRL, where 55 percent of the workload in 1961 was devoted to BuShips, BuWeps, and ONR contractors and resulted in interference with USRL's work in providing standards and developing techniques. In the case of USRL, an examination of the charter shows that prototype and preproduction testing can be considered a legitimate part of the Laboratory's mission. However, as has been pointed out in Chapter 3, the overall workload at USRL has been steadily and rapidly increasing over the past several years. The

situation is now approaching the point where a decision must be reached whether USRL should continue to handle all the prototype and preproduction testing now requested of it. If so, the necessary additional manpower and facilities must be provided. If not, the Bureaus must take steps to provide their own facilities.

The current trend toward the development of large, complex sonar systems for surface ships and submarines has added a new dimension to the problem of transducer calibration. Whereas formerly a transducer could be isolated and tested separately in a calibration facility, such procedures have become inadequate for prototype and preproduction testing of the newer sonar systems whose transducers cannot be properly evaluated apart from the other components of the equipment. For example, troubles have been encountered in the AN/SQS-26 program as a result of the lack of adequate system tests prior to actual shipboard installation. The practical difficulties associated with the installation of a complete system aboard a "general-purpose" calibration barge make it imperative to search for other ways of solving the problem of prototype and preproduction testing of new major sonar systems.

Production Acceptance and Maintenance Testing

This category consists of routine tests on fleet production items. The scope of the tests is of course far narrower than that of prototype and preproduction tests, but the number of units involved is far greater. Both acceptance and maintenance tests of surface ships and submarine sonar transducers are run at naval shipyards. At the present time Boston employs a barge in the harbor. Mare Island has an 18-ft-diameter indoor tank and a 60-ft-diameter by 25-ft-deep outdoor tank, and Pearl Harbor has a barge on a curtained-off section of the harbor for calibration. Production-acceptance tests of airborne sonar transducers and torpedo and mine transducers are for the most part run in contractors' plants. In the case of sonobuoys, 32 samples out of each lot of 800 are sent to the Sonobuoy Test Facility in the Gulf of Maine for test. However, because of facility limitations, only rudimentary acoustic tests have been run at Maine; some of this testing has been done at USRL. No acoustic maintenance tests are run on sonobuoys. Arrangements are being made to have the Boston and Mare Island Naval Shipyards calibrate AN/AQS-10 helicopter-dipped sonar transducers at the time of overhaul.

The situation existing in the shipyards is critical. The Boston Naval Shipyard handles about 50 percent of the transducer-calibration load, while Mare Island and Pearl Harbor handle about 30 percent and 20 percent, respectively. Boston makes about 8000 to 9000 calibrations per year on overhauled transducers, exclusive of production testing. The estimate for the 1965-1970 period is 15,000 to 20,000 per year. The staff at Boston works a 48-hour week. There are three shifts per day, and operation is six days per week. Although production and maintenance workloads should be predictable well in advance, it appears that insufficient attention has been paid to the matter of shipyard testing. The anticipated doubling of the workload in already loaded facilities constitutes a problem which demands immediate attention.

SUMMARY

The trend toward larger and more powerful sonars is creating an increasing demand for deep-water transducer-calibration facilities capable of handling larger and heavier loads and of supplying more driving power. In addition, the trend toward deeper operating depths is generating ever-increasing requirements for high-pressure facilities, both for acoustic measurements and for mechanical tests, to ascertain the ability of equipments to withstand the deep-ocean environment. A survey of the current and projected transducer-calibration situation has amply confirmed these trends and has revealed other problem areas which require immediate attention.

The transducer-calibration station at Lake Pend Oreille, Idaho, the Navy's only deep-water inland facility, is not capable of handling the currently generated workload, and the situation can be expected to become worse in the future. An additional deep-water facility readily accessible to the eastern laboratories is urgently needed. The most suitable location is Lake

Seneca, New York. Needs also exist for specific local open-water facilities at several laboratories, as discussed in preceding paragraphs.

Equally serious is the requirement for adequate high-pressure test facilities. At present no adequate facilities exist for high-pressure acoustic measurements on large or even moderate-sized transducers. The proposed USRL 40-ft spherical tank will provide a significant capability in this area, and as soon as its feasibility is proved, procurement should proceed as rapidly as possible. Additional pressure tanks, both for acoustic measurements and nonacoustic mechanical tests, are required at major laboratories concerned with deep-ocean equipments.

There are equipments, particularly arrays designed to operate in the deep ocean, whose calibration requirements exceed the capabilities of present or proposed inland high-pressure facilities. These will require calibration at sea, chiefly at AUTEC, and will need a stable platform in order to achieve sufficient accuracy. The present effort by NRL to develop such a platform should be continued at high priority.

Another serious problem is the interference caused by tests for Bureau contractors at Navy R and D laboratories. This is caused in part by lack of adequate facilities on the part of the contractors and in part by the failure of the Bureaus to make adequate plans for the conduct of prototype and preproduction tests. The initiative of several of the contractors in developing adequate facilities of their own is recognized and encouraged. Further effort in this direction is required in order to reduce the load on Navy laboratories.

The laboratory most seriously affected by prototype and preproduction testing is USL, which has been spending about 75 percent of its effort on these tests. In order to salvage its own R and D program, USL requires that this workload be cut as soon as possible to 25 percent or less.

The USRL workload has been increasing at a rapid rate over the past few years, a large part of it consisting of tests for Navy contractors. While these tests can be considered to be a legitimate part of the USRL mission, it will soon be necessary either to expand USRL's facilities or to have much of the work done elsewhere.

The development of large modern sonar systems for surface vessels and submarines has introduced a new element of complexity into the transducer calibration situation, namely, the requirement to test the transducer as an integral part of a complete system rather than as an isolated piece of acoustic equipment. For prototype and preproduction tests of new major sonar systems, additional special-purpose facilities will be required above and beyond the general-purpose facilities currently available or planned for the future.

A critical situation is developing at the three naval shipyards, Boston, Mare Island, and Pearl Harbor, at which calibrations of both new and overhauled fleet sonar transducers are run. These facilities are already loaded to capacity, and the present workload is expected to double by 1970. To handle the increased workload either additional capability must be provided to the present shipyards, or facilities must be established at other shipyards.

CHAPTER 5

SOLUTIONS TO THE PROBLEM

In this chapter the USAG states its considered conclusions drawn from its study and analysis of the problem. A summarized set of recommendations for specific actions by the appropriate organizations (BuShips, BuWeps, ONR) is presented under the separate heading of "Recommendations."

SUMMARY OF THE BASIC INADEQUACIES

The major basic problem areas are, in brief:

1. Since special facilities for prototype and preproduction testing have not in the past been provided, either existing R and D facilities are being used for this purpose at the expense of R and D work, which is severely hampered as a result, or major systems are being installed with no systems test before final installation.

2. Important R and D laboratories do not have adequate deep-water facilities.

3. High-pressure acoustic tank facilities now in existence are not adequate to handle present and future requirements for calibration of deep-water elements.

The preceding analysis, Chapter 4, has shown the inadequacy of presently available transducer calibration facilities to handle the current workload and has given some indication of the trends that may be anticipated in the future. In addition to increasing the workload demand, developments which are being carried out to meet new operational requirements are continually imposing more severe technical requirements on calibration facilities. The increasing size and complexity of sonar systems is felt not only in research and development but also throughout every stage of fleet procurement and maintenance programs. Since in many instances the only suitable calibration facilities are found at the research and development laboratories (and often these are inadequate), a problem of interference has arisen between R and D programs and fleet procurement programs.

The ideal solution to this problem would of course be to provide adequate facilities for all categories of testing, from R and D through all stages of procurement and maintenance. The implementation of such an ideal solution, however, would not be practical from an economic point of view, and it is therefore imperative to examine the situation carefully with a view to recommending such practical partial solutions as will enable the major needs to be met in the most efficient way. It will be convenient to discuss these solutions within the framework of the major categories of testing outlined earlier in this report. It must be recognized, however, that areas of overlap exist between categories.

CONCLUSIONS

Standards and Techniques

This category has been discussed in Chapter 4 and needs no further discussion here other than to emphasize that the maintenance and calibration of transducer standards and the research and development on new measurement techniques and instrumentation must continue to be the prime function of USRL and must never be impaired by increased demands upon USRL for other work.

Inland Deep-Water Facilities - Earlier discussion, in Chapter 4, has established the need for deep-water lakes for the calibration and testing of transducers which require large volumes of water, and of those devices, such as VDS sonars, submarine sonars, the newer airborne dipped sonars and sonobuoys, torpedoes, mines, etc., which are required to operate at considerable depth. The Navy at the present time has only one such deep-water inland facility – the NEL facility at Lake Pend Oreille, Idaho. This is undoubtedly the best calibration site in the United States. However, as has been pointed out, the Lake Pend Oreille facility, in spite of repeated expansions and improvements and the establishment of two-shift operation for five months out of the year, is not capable of satisfying all of the Navy's deep-water calibration requirements. Another factor to be considered is its remoteness from the eastern laboratories, especially NRL and USL, which have major needs for a deep-water facility. It is a matter of great importance that a suitable deep-water facility be established in the eastern part of the U.S.

Surveys have shown that the most suitable sites in the east are located in the Finger Lakes region of New York. Seneca Lake, with a maximum depth of about 600 ft and with an inland-waterway connection to the ocean, is the best. Cayuga Lake is the second best. The importance of these lakes has already been recognized by private contractors. The General Dynamics Corporation has established a barge on Seneca Lake, and the General Electric Company has a barge on Cayuga Lake.

Within the Navy, NRL has taken steps to satisfy its urgent needs by outfitting a mobile test barge and moving it to a location on Seneca Lake, where modest dock facilities have been leased. Ideally each major laboratory should have its own calibration and test facilities, but the number of suitable lakes available and the cost of facilities make this arrangement impractical. Therefore it appears necessary that the NRL barge on Seneca Lake be developed and expanded into a permanent calibration station whose services will be available to all Navy in-house and Navy-supported nonprofit laboratories having need for deep-water calibration, and to private contractors to the extent to which scheduling will permit.

Serious consideration has been given to the matter of who should operate the recommended Seneca Lake facility. It is logical that NRL should continue to operate its barge on the lake during the "break-in" period, for a year or so, until plans can be made for developing the permanent facility. However, NRL does not wish to be burdened with the responsibility of permanently operating a service facility for other laboratories. Also, it does not seem advisable to attempt to set up a new organization to do this job. On the other hand, such a mission is clearly within the charter of USRL. In fact, at the present time USRL is doing this type of work for the material bureaus, Navy laboratories, and private contractors. The organization is well versed in the technology of transducer calibration and is experienced in the operation of calibration facilities. Since the facility would be used by a number of different clients, it seems logical that USRL should be given the responsibility for its operation. It is therefore concluded that during the interim period while NRL is establishing and operating its barge, USRL should plan in detail an expansion of this facility and prepare to take over the operation of it by the end of calendar year 1963. It should then continue to expand the facility to keep up with the Navy's R and D requirements to the limit of the capabilities of the site.

High-Pressure Tanks - Special large-volume high-pressure tanks, both for acoustic and nonacoustic tests, are absolutely necessary for an adequate research and development program. They are also needed for contractor development and for prototype and preproduction testing. Because of the high costs of such tanks, this is one area in which the Navy will have to furnish facilities for contractor development, testing, and calibration.

The most urgent needs for nonacoustic tanks have been voiced by NRL and USL, as has been discussed in Chapter 4. These tanks should be funded and procured as soon as possible.

The situation with regard to high-pressure acoustic tanks is more critical. The USRL-proposed 40-ft spherical tank for acoustic tests at pressures up to perhaps 3000 to 5000 psi

will fill a major need and the proposal is strongly endorsed. This tank will be a unique facility, and it undoubtedly will be used for many purposes and for many clients. In view of the shortage of space at USRL, it is suggested that serious consideration be given to locating this tank at the shore facility of the Seneca Lake calibration and test station (proposed above as expansion of NRL barge).

It is anticipated that with continued emphasis on deep-ocean operation, the pressure-tank facilities of USRL, both present and planned, will not be adequate to meet the need. It is therefore incumbent upon BuShips and BuWeps to examine carefully their development and procurement programs in order to ascertain the need for additional high-pressure acoustic test facilities. Because of the long time interval required for the design and fabrication of such tanks, the need for them must be anticipated as far in advance as possible. It appears logical that as additional tanks are needed they should be procured and located at the various major Navy R and D laboratories.

Local Open-Water Facilities - Local facilities, including tanks and ponds, will continue to be needed as much in the future as in the past. For efficient operation, each laboratory must have local facilities for back-yard work. A great deal of work can be done in relatively small tanks and ponds. Every effort should be made to utilize these facilities to the utmost and to extend their usefulness to the limit.

It is believed that the major requirements for local open-water facilities for R and D work can be met if the needs discussed in Chapter 4 are satisfied. Specifically, these are:

1. Improvement of the USRL site at Leesburg, Florida. The development of this site should be primarily for the purpose of providing improved capability for work on standards and calibration techniques, and should consist of such items as a more stable platform, automatic instrumentation, and facilities for the development of near-field techniques.

2. Reduction of the prototype and preproduction workload at the USL Dodge Pond facility to a maximum of 25 percent of the facility time. The accomplishment of this objective depends upon a solution of the problem of prototype and preproduction tests, which will be discussed in a later paragraph.

3. Development of the NAVAIRDEVCEN quarry site at Oreland, Pennsylvania.

Open-Ocean Facilities - Deep lakes provide moderate pressures and free-field conditions. Pressure tanks can provide pressures in excess of those obtainable in lakes but are restricted in volume, range, and transducer size capacity. Only the open ocean can provide simultaneously the conditions of very high pressure and free field. In general, the deep-ocean type of facility can be unique in providing the capability of handling very large units at depth. AUTEC is expected to provide the very-much-needed facility for testing and calibrating complete systems as installed in a ship or submarine. Tests at very great depths, particularly of large transducers and arrays, can be made when a facility such as FORDS becomes available.

Although the acoustic measurement range to be included in AUTEC provides a valuable capability for certain deep-water measurements (installed systems), it must be recognized that for a number of reasons this range cannot serve as a substitute for the recommended Seneca Lake facility. In the first place, the environmental and test conditions cannot be as precisely controlled. Second, logistics problems will be much more severe. Third, the workload capacity of an open-ocean facility is considerably more limited. Fourth, there will be a problem of interference from other activities in the AUTEC area. In general, only those measurements which cannot be done elsewhere should be performed at AUTEC.

The large projectors and hydrophone arrays associated with long-range, low-frequency surveillance systems, such as Artemis and Trident, pose special problems. These transducers, in general, are completely assembled only when installed in the permanent positions. Therefore, only an in-place calibration can be made on the complete units. The component parts of the arrays, however, will need to be individually tested and calibrated prior to final installation.

Contractor Development

As has been pointed out previously, the increasing demands upon Navy R and D facilities make it mandatory that contractors provide themselves more and more with facilities to meet their own calibration requirements, especially with respect to open-water facilities and small pressure tanks. The initiative of three contractors in establishing deep-water facilities is commended. The one area in which the Navy will probably have to continue to provide services is that of high-pressure acoustic tests on transducers of appreciable size.

The development of new major sonar systems poses a new set of problems, not only for contractor development, but also for prototype and preproduction testing. These problems have been mentioned in Chapter 4 and will be discussed further in the next paragraph.

Prototype and Preproduction Testing

The category of prototype and preproduction tests have developed into one of the chief bottlenecks in the entire transducer calibration situation. There are two reasons for this problem. First, the amount of testing required for a modern sonar system such as SQS-26 or BOQ-2 is vastly greater than was formerly required on smaller, simpler systems. Not only is more facility time required for a given prototype transducer, but also, as for SQS-23, a number of different transducer models by different manufacturers may require evaluation and test. The second reason is that no calibration facilities have been set up specifically to handle prototype and preproduction testing. The result has been a severe imposition on the R and D facilities of Navy laboratories, especially USL and USRL.

There are four possible solutions to this problem: (a) expand USRL by the addition of a prototype and preproduction testing division at a new location with new manpower, (b) expand the other in-house R and D calibration facilities with additional manpower and either new or more highly developed locations, (c) set up, under the auspices of the material bureaus, one or more new organizations at new locations to handle the workload, (d) require new procurement contracts to include provision of facilities for prototype and preproduction testing by the contractor, either by construction or subcontract.

Serious consideration has been given to these four possibilities. The first has the advantage of tieing the new group to an already existing professional standard and calibration organization. The second has the advantage of tieing the expansion to the laboratories doing work of the same nature. Some of the transducers to be evaluated were developed as the direct result of specific R and D programs at the laboratories. The third possibility has the advantage of tieing the testing directly to the cognizant bureaus which are responsible for the developments. It faces a severe problem, however, in the establishing of entirely new organizations without previous experience in calibration work. The fourth possibility would probably be very expensive, at least at the outset, since a considerable number of facilities might be required. In the long run, however, these facilities would become part of the competitive cost picture, and the national capability would expand.

Eventually, if sonar work continues to expand, several of these steps may have to be taken. For the immediate future, however, a specific decision must be made. Although none of the four possibilities offers an ideal solution, the most logical choice appears to be the first. Since it has already been recommended that USRL operate a new R and D facility on Seneca Lake, it would seem that the most efficient way to carry out the prototype and preproduction testing program would be to establish an additional facility under the same management in the same area. Under this plan administrative problems would be simplified, the two activities would complement one another, and the same shore facilities could be used for both purposes. It is fully realized that this step would require for USRL a major expansion in both personnel and management structure, as well as a somewhat new and additional function concept.

It is not expected that the Seneca Lake facility would handle all prototype and preproduction testing. In the first place, transducers which are integral parts of large assembled systems

will have to be tested elsewhere. Secondly, it is anticipated that the workload would, in any case, exceed the capacity of the new USRL facility, and therefore other in-house R and D laboratories would be required to share in the testing of those contracted items in which they have an R and D interest, up to about 25 percent of their capacity. When economically advisable, development testing at contractors' facilities should be extended through the prototype and preproduction stage, with supervision of the final tests by representatives of Navy laboratories (a partial application of the fourth possibility mentioned above).

Since it will take considerable time to develop the prototype and preproduction facility at Seneca Lake, consideration must be given to interim measures for alleviating the present acute problem. A certain amount of redistribution of work should be made among the several laboratories in order that the load may be shared more equitably. Specifically, the prototype and preproduction testing at USL should be tapered off, that of USRL at Orlando should remain about as it is, and that at other facilities should be increased. Of course, assignments should be made with due regard for the technical capabilities of the different facilities. When this results in the necessity for these laboratories to work extra shifts in order to carry the workload of both R and D and preproduction testing, the bureaus must provide and fund extra billets and/or overtime.

As another interim measure, contractors' facilities should be used to the greatest extent practicable for prototype and preproduction testing. Also, after the R and D facility at Seneca Lake is in full operation, a certain amount of its time – say 25 percent – can be made available for this purpose.

Facilities for Testing of Major Sonar Systems

Some of the major sonar systems now in existence or under development, and in particular those planned for the future, are of such size and complexity that it is impossible to make complete tests except as an assembled system. The very high cost of each of these systems makes it appear worthwhile to provide a special platform (barge or ship) for the prototype and preproduction testing of each such system. Furthermore, with proper planning, the platform can be made available in time to be used by the contractor for tests during the development and assembly of the system.

Each system may be undergoing testing for several years, and existing facilities are not adequate to handle this problem. If a major system were to be placed in an R and D facility, there would not be room for any other work. A separate platform for each major system appears to be the only reasonable solution.

Navy Shipyard Facilities

The severe workload problem in Navy shipyards has been discussed in Chapter 4. In view of the expected aggravation of the problem in the years ahead, steps toward a solution must be taken as soon as possible. Although the present facilities are adequate from the standpoint of depth and range for the transducers now being tested, an increased use of tanks would help to alleviate the heavy schedule. The use of tanks and near-field methods would permit measurements to be made under stable conditions of low ambient noise and isothermal water. Multiple tank set-ups could be used to reduce the need for multiple shifts. The requirements for skilled supervisory personnel would be reduced, since a single supervisor could oversee several tanks simultaneously. It is feasible to install tanks indoors and thus provide for year-round operation, independently of weather conditions.

Another problem which requires solution is the need for making "in-place" calibrations of transducers as installed on ships and submarines. It would be very desirable to have the capability of performing such calibrations in the immediate vicinity of shipyards, thereby avoiding the necessity of taking the ship to some remote calibration range. It may well be that near-field techniques can be adapted to this purpose. If it has not already initiated such action,

the Bureau of Ships should undertake the development of suitable techniques for "in-place" calibrations at shipyards.

SUMMARY

The failure to provide adequate facilities for contractor development and tests and pre-production and prototype testing is the cause of much of the present difficulties. How best to find a remedy for this inadequacy is perhaps the major problem to be faced and is one for which it is not easy to develop an acceptable solution. Unless such an adequate solution is found, one may be sure the R and D program will continue to suffer.

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APPENDIX A

SOURCES OF INFORMATION

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DRL, University of Texas

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Dr. C. W. Horton

DTMB

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Mr. A. O. Sykes

Hudson Laboratories

Mr. H. Sonnemann
Mr. S. Steiner
Mr. J. Warren

ACTIVITIES

Aerojet General Corporation
APL/UW
Bell Telephone Laboratories, Whippany
Bendix Corporation, Pacific Division
Bendix Corporation, Research Laboratories
Chesapeake Instrument Corporation
Clevite Corporation
Daystrom, Incorporated - Electric Division
DRL, University of Texas
DTMB
Edo Corporation, Long Island
Emerson Electric Mfg. Co.
General Dynamics/Electronics
General Dynamics, Convair
General Dynamics, Electric Boat Div.
General Electric Co., Syracuse and Utica
General Electric Co., Light Military Electronics Dept.
General Instruments Corporation
Grumman Aircraft Engineering Corporation
Gulton Industries, Inc.
Harris Transducer Corporation
Hazeltine Corporation, Hazeltine Electronics Div.
Hoffman Electronics Corporation, Hoffman Laboratories Div.
Hudson Laboratories, Columbia Univ.
Hughes Aircraft Co.
Lamont Geological Observatory, Columbia Univ.
Lockheed Aircraft Corporation
The Magnavox Company
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The Martin Company
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MELPAR, Inc.
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Sangamo Electric, Springfield
SIO/Univ. of California
Sprague Electric Co.
Sparton Corporation, Sparton Electronics Div.
Stanford Research Institute
Sylvania Electric Products, Inc.
Texas Instruments, Inc.
USL
U.S. Coast Guard HDQTS
U.S. Naval Shipyard, Pearl Harbor
U.S. Naval Shipyard, Mare Island

U.S. Naval Shipyard, Boston
U.S. Naval Shipyard, Philadelphia
U.S. Naval Shipyard, Bremerton
U.S. Naval Torpedo Station, Keyport
USRL
Vitro Corporation of America, West Orange, N.J.
Vitro Corporation of America, Silver Spring, Md.
Westinghouse Research Laboratories, Pittsburgh
Westinghouse Electric, Baltimore
WHOI

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